UNITED NATIONS ENVIRONMENTAL PROGRAMME

THE INTERNATIONAL SATELLITE LAND-SURFACE CLIMATOLOGY PROJECT

F. BECKER H.-J. BOLLE P. R. ROWNTREE

COMMITTEE ON SPACE RESEARCH (COSPAR)
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THE INTERNATIONAL SATELLITE LAND-SURFACE CLIMATOLOGY PROJECT (ISLSCP)

ISLSCP-Report No. 10

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PREFACE

This brochure was written on the suggestion of UNEP to inform a broader community about the goals and the present status of the International Satellite Land-Surface Climatology Project (ISLSCP). Due to the wealth of information that is now available the scope of the brochure broadened as the work on it proceeded. The authors therefore hope, that also scientists who are already involved in the ISLSCP will find some useful information in this publication. In order to make the text clearer for those readers who are not interested in details, all references to the literature except for the figures have been omitted. The reader is referred to the bibliography at the end of the brochure in order to find more detailed information.

The brochure would not have been possible without the enthusiastic and continuous efforts of many colleagues in providing the authors with information and in suggesting improvements. We would like to thank here especially those colleagues who contributed sometimes even unpublished illustrations and preprints of their papers, and those who carefully read and corrected the draft. Dr. Massimo Menenti and the former Secretary General of IAMAP, Mr. Stanley Ruttenberg, were involved in the early layout of the brochure. We would furthermore like to express our gratitude to Ms. Ute Katergiannakis and Christine Ziehmann-Schlumbohm for their editorial work and Ms. Paola Pierani, Manuela Boguslawski, Martina Scholz and Jutta Wedel who patiently worked several times through the different and at the beginning very heterogeneous drafts of the manuscript of this brochure. Ms. Sabine Fleischer designed and completed many of the drawings; Mr. Wolfgang Müller did much of the photographical work.

December 1987

F. Becker, Strasbourg
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INTRODUCTION

WHY WE NEED AN INTERNATIONAL SATELLITE LAND-SURFACE CLIMATOLOGY PROJECT

One wholly new vista that space technology has opened for mankind and science is an overview of the whole Earth every half-day or, if sophisticated instruments with high spatial resolution are applied, every month. The information that can thus be obtained has a tremendous volume and it is an open question how it can be beneficially digested and used.

This revolutionary new view of the Earth from space is accompanied by the development of powerful physical-mathematical models which attempt to describe the physical processes in the world around us.

It is natural to think about the combination of the two inventions, space-borne observation system and model, especially if problems of global dimensions are involved. The first for whom such problems arose were the meteorologists, who for some time have assimilated satellite data into their global weather forecasting models. More recently it has become necessary to construct models of our climate system in order to assess the impact which the rising CO_2 and other trace gas concentrations may have in the future on our environment. Additional land-surface data are needed for these models, because of their more detailed representations of surface processes. Moreover, in the course of recent studies it emerged that changes in the land-surface characteristics, especially in hydrological properties and some biologically-controlled processes, have significant impacts on the atmospheric circulation. Such changes can be caused if the atmospheric dynamics change for other reasons. Thus there exists an interrelation between the large-scale land-surface properties and climate, and so a possibility of feedbacks, through which land-surface modifications induced by climate changes may accelerate or decelerate these changes. This has to be explored thoroughly, because it is a central question within the climate complex.

For the study of such processes, information is needed about the real world in order to

- develop mathematical approximations which correctly describe the processes that occur,
- check on the realism of computer models at least on short (interannual) time scales,
- run computer models in order to identify the critical parameters in the system and to analyze the impact upon the system if such parameters are changed, and finally
- initialize computer models if they are used to predict future changes.

A closely related question is how the land-surface reacts to changes of the climate, how the vegetation reacts if temperatures and precipitation patterns change and how agriculture, water and renewable energy resources are affected by climate variations, which may be enforced by the raising amount of radiatively active gases in the atmosphere and modification of land-surface characteristics.

An additional complication is introduced into the climate system by the action of mankind. Since man is changing the biota of the continents to a large extent, he may already interact with the climate system through alteration of the surface condition. There would be only one way of assessing these changes rapidly and on a global scale: by means of satellite observations. It presently seems promising that measurements from satellites are capable of detecting and quantifying modifications of the land-surface that may become evident in changing soil properties, vegetation, erosion or desertification. There are also models under development which aim to predict environmental and e.g. yield changes in dependence of climate trends. It is this area that in the first instance motivated scientists to improve the methods of satellite data evaluation in order to provide diagnostic and model-supporting data for climate impact studies.

Different scientific groups have already commenced production of data sets relevant to these needs. However, the algorithms used in their generation need to be validated in different regions of the Earth. In order to be useful for numerical simulations the data sets must also be prepared in a way compatible with the requirements of the global and regional climate models.

The production of data sets and the development of rationales how these data are used in models and for diagnostic studies requires at the present stage still thorough basic research on the processes in which land-surfaces are involved. Pilot studies with retrospective data sets can assist in the assessment of the role that satellite data may play in the future. Also scientifically less attractive aspects of data processing and archiving have to be stimulated. There are only limited resources for such a task. It is therefore necessary that the steps towards a global satellite land-surface climatology be internationally co-ordinated. For this purpose the ISLSCP is needed.

HOW ISLSCP WAS BORN

When it became apparent that global data sets of land-surface characteristics could be derived from satellite measurements, and also that a need for such data existed in the World Climate Programme (WCP), the Committee on Space Research (COSPAR) and the International Association of Meteorology and Atmospheric Physics (IAMAP) jointly approached the United Nations Environmental Programme (UNEP) to support the co-ordinating activities of the International Satellite Land-Surface Climatology Project (ISLSCP) within its World Climate Impact-Studies Programme (WCIP). UNEP provided funds for the initial phase of

ISLSCP and at two meetings during summer 1983, one at the National Center for Atmospheric Research (NCAR) in Boulder, USA, and one at the University in Innsbruck, Austria, the goals and the research strategy of ISLSCP were developed. In total, more than 100 scientists representing 32 countries worldwide came together to define the project. These two meetings resulted in a report to UNEP on the *Development of the Implementation Plan for the International Satellite Land-Surface Climatology Project (ISLSCP) Phase I.*

Since the same data which are useful for physical climate impact studies are also needed for climate research, and here especially climate modelling, the Joint Scientific Committee (JSC) for the World Climate Research Programme (WCRP) also became interested in the ISLSCP in connection with its Global Data Set Project. It described the requirement for this project in the *First Implementation Plan for the WCRP.*

Even if there were no climate problem, it is certainly timely to study in its own right in more detail the land-surface processes and the changes that occur on a global scale due to the interaction of mankind with nature. Only on a firm scientific basis efficient measures can be taken in the future to protect nature and to initiate counteractions to its irreversible change. In view of the growing concern about the changes detected so far the International Council of Scientific Unions (ICSU) has initiated a research program on Global Change, the International Geosphere-Biosphere Program (IGBP). IAMAP jointly with the International Association on Hydrological Sciences (IAHS), proposed through the International Union of Geodesy and Geophysics (IUGG) at its assembly in Vancouver, 1987, that a Land-surface — Atmosphere — Vegetation — Interaction Program be established within IGBP. Within this program the interactions between the biosphere, the soil and the atmosphere should be investigated on a broader and interdisciplinary basis with special emphasis on the governing hydrological processes involved. ISLSCP would necessarily be a major component of this program.

In its initial Phase ISLSCP is additionally sponsored by the Bundesministerium für Forschung und Technologie (FRG), the Centre National d'Etude Spaciales (CNES, France), the European Space Agency (ESA), the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), and jointly by the World Meteorological Organization (WMO) and the International Council of Scientific Unions (ICSU) through its Joint Scientific Committee for the World Climate Research Programme (JSC). Several national institutions supported the participation of their scientists in ISLSCP meetings. The COSPAR Secretariat handled the administrative matters and the IAMAP Secretariat the publication of the first four reports until 1986.

THE GOALS OF ISLSCP

ISLSCP was established to conduct basic research to improve our understanding of the processes involved in the interactions between the biosphere and the atmosphere with the aid of measurements from satellite. It is part of more general efforts to clarify the role that changes in land-surface characteristics play in climate. The prime goals of ISLSCP are to direct research into the deduction of climatically relevant information about the land-surface from the measurements made by different satellite systems, and to prepare the ground for a multi-year homogeneous and validated data set of several key quantities which can be used in climate studies. A research programme that addresses this problem globally may develop in four components:

1. Adaptation of existing soil-vegetation-atmosphere models and their refinement with respect to hydrometeorological and plant-radiation interactions.

2. Inference of area-averaged physical-biological land-surface characteristics from spectral radiances measured by satellite-borne instruments.

3. Validation and calibration of the methods that are used to extract this information and of the parameterization schemes used in climate models by means of direct measurements at the ground.

4. Sensitivity studies of interactions between the land-surface and climate using climate models in order to narrow down the requirements for type, accuracy and frequency of the satellite observations.

The radiation leaving the land-surface is modified to some degree by the atmosphere to produce a signal in the instruments flown on board of the satellites. In order to relate the signals, which are taken at different times and with different instrumentation, to the physical properties of the land-surface, they have first to be transposed into absolute radiance values. The inference of land-surface quantities from the signals measured at different wavelengths then requires the application of evaluation procedures, called "algorithms", which also correct for the interference of the atmosphere.

The information needed for climate studies can consist of "primary deduced quantities", like the spectral surface reflectance, or of data sets derived in a more complex fashion from several different measurements and including also *a priori* information such as the terrain profile or soil type. Thus we have to deal with a hierarchy of data sets and evaluation methods of varying sophistication.

When the desired product is finally obtained, its accuracy has to be established. This can only be done by direct measurements at or near the surface. Validation experiments therefore play a major role in ISLSCP. If, ultimately, generally accepted, standardized and validated evaluation methods become available, institutions have to be found to implement the algorithms and to produce the data sets operationally. The data can then be offered for climate studies. It will therefore be some time before the research community can be assured of quality data sets derived from satellite-borne instruments. In the meantime preliminary data sets will become available and ISLSCP will inform the research community about their validation status.

HOW THE PROJECT IS PRESENTED IN THIS BROCHURE

This brochure addresses readers in the wider scientific community and would also like to attract the attention of decision-makers in potential sponsoring agencies and administrations. From the presentation there should emerge not only the interdisciplinary character of the project, its relevance for a number of environmental problems and the present capability for assessing from satellites physical properties of the land-surface including its vegetation, but also the problems which exist with the quantitative evaluation of satellite data and the necessity of performing accompanying ground-based studies. The brochure cannot go into much detail. Therefore, for a more scientific description of the project, the reader is referred to the documents listed at its end.

Since ISLSCP is not concerned with standard land-use applications of satellite data but with the problem of deducing physical properties of the land-surface, the first section deals in general way with this problem in the context of climate studies. The second section then gives an overview of the presently available products derived from satellite measurements with a few selected examples. The techniques that lead to such products are discussed in more detail in the third section, which also addresses the improvements necessary to make satellite observations more efficient. In the fourth section the scientific rationale of product verification by means of measurements at the surface is explained. The application of validated ISLSCP data sets in climate studies is the topic of the fifth section and finally an estimate is given of the timetable from now until the availability of validated data sets deduced by generally accepted and standardized evaluation methods.

1. THE ROLE OF LAND-SURFACE PROCESSES IN CLIMATE AND THE SCIENTIFIC RATIONALE OF ISLSCP

1.1. How the land-surface influences the global circulation of the atmosphere by exchanging energy, momentum and moisture

During the last two decades there has been a growing awareness of the importance of land-surface processes for climate. According to Charney's 1975 hypothesis on the role of surface reflectivity (or albedo) in the dynamics of deserts, the absence of vegetation leads to a high surface albedo which "contributes to a net radiative heat loss relative to its surrounding... the resultant horizontal temperature gradients induce a frictionally controlled circulation which imports heat aloft and maintains thermal equilibrium through sinking motion and adiabatic compression".

An increase in albedo from 0.2 to 0.3 will typically reduce the net downward surface (solar and longwave) radiation in the subtropics in summer from about 160 to 130 Wm^{-2}. Of at least comparable significance, however, is the effect of the net incident radiation at the top of the atmosphere, which will be almost as large as that at the surface. Over land near 30° N in summer this net radiation is about 30 Wm^{-2} so that such an albedo increase will reduce it almost to zero (Figure 1.1). The high albedoes of the Sahara — together with the high surface temperatures and the lack of water vapour in the atmosphere both of which increase the longwave radiative cooling to space — make it a heat sink even in summer. It was the evidence of this from early satellite data which led Charney to his hypothesis that such a heat sink in low latitudes must be compensated by atmospheric subsidence which tends to maintain the aridity of the atmosphere and surface and so also the lack of vegetation — completing a potentially important positive feedback loop.

The surface albedo directly affects the amount of energy absorbed by the surface. Redistribution of this energy from the surface is by several processes: conduction both into the soil and upward into the air, evaporation of moisture into the air, and longwave radiation — all strongly dependent on surface temperature. Variations in surface moisture availability impose a large spatial and temporal variation on these processes. The surface resistance to evaporation varies from small values for wet vegetation to high values for drought conditions in vegetated terrains and for deserts. Models of the atmospheric circulation show that this surface moisture source is important for atmospheric dynamics and for rainfall. Moreover through its impact on rainfall it interacts with the albedo feedback discussed above. Though the soil moisture near the surface may be sensed remotely, the evaporation rate can depend on the moisture near plant roots well below the surface. However, because of its influence on surface temperature, it may be possible to estimate evaporation by sensing the longwave radiance in the "water vapour window" — the region of the spectrum in which water vapour absorbs and emits only very

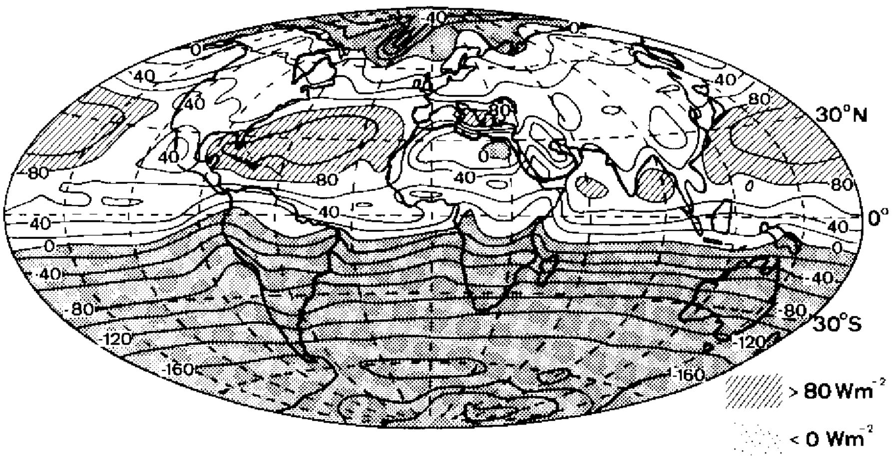

Fig. 1.1 Net radiation average at the top of the atmosphere for June through August 1979 (after D. L. Hartmann et al., 1986).

weakly, so that the surface temperature is the dominant factor determining the radiance seen from the space.

The contrasting roles of albedo and evapotranspiration in determining surface temperature are illustrated by the data from Tunisia in Figure 1.2. Over the bare ground of the Chott Djerid, radiometrically sensed surface effective temperatures decreased with increasing albedo whereas over vegetation the opposite trend was observed: lower albedoes being associated with more vegetation and therefore with more actively transpiring and so cooler plants (the range of albedo for vegetation conditions is from about 0.1 for tropical rain forests to about 0.4 for dry sandy semi deserts).

The longwave radiation from the surface depends not only on the temperature but also on the emissivity of the surface, which though near unity for most vegetated surfaces, falls substantially below this for some sands. This complicates the interpretation of remotely sensed radiances. Without further information one cannot tell if the effect demonstrated in Figure 1.2a is due to the higher albedo surfaces being cooler or having lower emissivity.

The land-surface also affects the atmosphere by exerting a frictional drag on the winds, which can modify the circulation, causing frictional inflow into low pressure regions. The surface also generates turbulence in the surface layer by the interference of vegetation and small scale orography (rocks, hills, mountains) with the flow. This turbulence enhances the transfer of heat and moisture between air

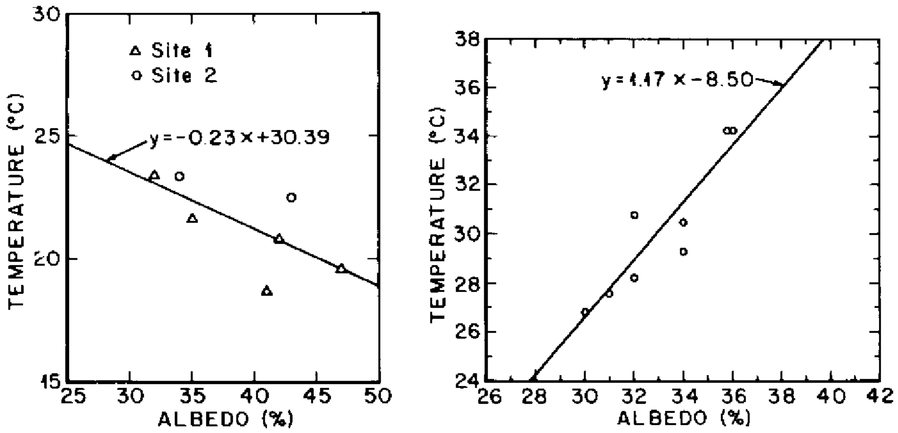

Fig. 1.2 a Left: Surface temperature plotted as function of the albedo for unvegetated areas at Chott Djerid (from G. Wendler and F. Eaton, 1983).

b Right: Surface temperature plotted as function of the albedo for plants in the semi-desert of Southern Tunisia (from G. Wendler and F. Eaton, 1983).

and ground. A smooth surface would thus tend to be warmer because of the reduced efficiency of heat transfer, and though an increase in wind speed due to the reduced surface drag will in part compensate for this, models do show a surface warming when surface roughness is reduced.

Due to the frictional drag the wind may also raise particulate matter from the surface which can result in large dust storms over dry continental areas. These aerosols, which can be transported over long distances, interact with the radiation field in a complicated manner depending on the optical properties of the particles. Desert aerosols generally have a cooling effect for the surface that may reach a maximum of 4K over the Sahel.

1.2. The sensitivity of the atmosphere to changes of the land-surface characteristics in general circulation models

The sensitivity of the global circulation to land-surface changes can generally be assessed only through experiments with models of the atmospheric general circulation. Only where impacts are large can observational studies carry much conviction and even then proof is difficult because of the inherent unpredictability of atmospheric behaviour.

In general circulation models (GCMs) the atmosphere and land-surface are commonly represented by fields of surface pressure, of wind components, temperature and moisture content for each of about ten atmospheric layers, of snow cover and of temperature and moisture content for one to a few soil layers. The time-dependent equations solved for the rates of change of the three-dimensional atmospheric variables include contributions for the moisture equation, due to advection and to sources and sinks of heat, moisture and momentum such as evaporation, precipitation, and turbulent moisture fluxes, respectively radiation for the temperature equation, latent heat release and turbulent heat fluxes. Processes represented in GCMs may vary significantly on spatial scales of the order of 1 km or less. These sub-grid scale variations must be represented in the model and therefore be expressed — or as one says "parameterized" — in terms of the model's variables on the GCM mesh scale of 50 to 300 km. For the interactions of radiation with the land-surface, acceptable accuracy may not be too difficult to achieve since the effects of surface albedo and emissivity are linear, so that space-averaged values can be used. This is far from true for the dependence of evapotranspiration

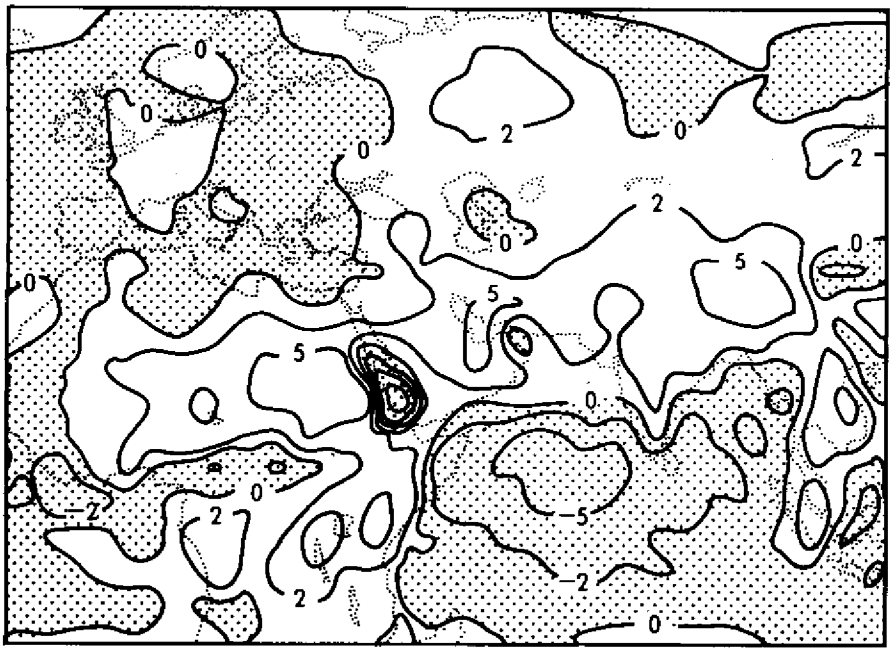

Fig. 1.3 Excess of precipitation with albedo of 0.1 relative to that with albedo of 0.3 at days 21-110 in July simulations with the Meteorological Office global low resolution 5-layer model. Areas with decreases shaded. Unit mm/day (from P. R. Rowntree and A. B. Sangster, 1986).

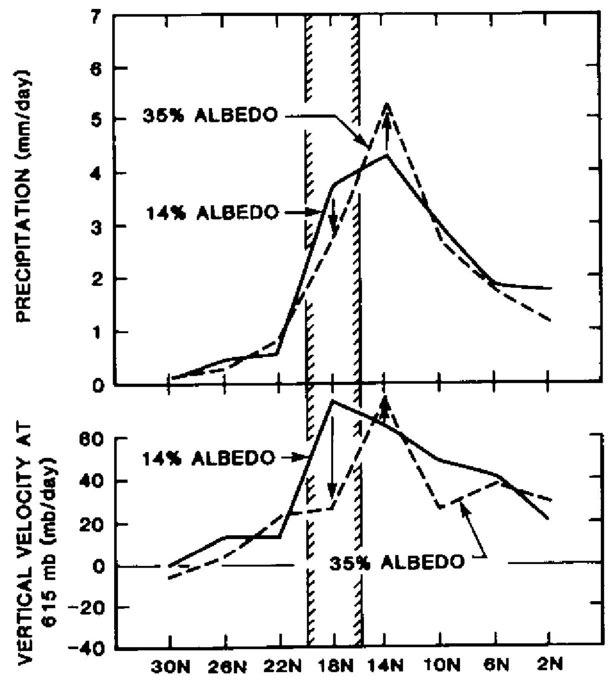

Fig. 1.4 Zonally averaged precipitation (top) and vertical velocity in the middle troposphere (bottom) over Africa, when the albedo in the Sahel (16—20°N) is increased from 0.14 to 0.35 (from Y. Mintz, 1984, after J. G. Charney, 1975).

of vegetation, soil characteristics, and hydrological processes, all of which, together with the water source (rainfall and snowmelt), are higly inhomogeneous over a grid box and involve non-linear processes such as soil moisture transfer. Thus, although at present only grid-box mean soil and vegetation characteristics are used in GCMs, sufficiently accurate parameterizations may require a knowledge of frequency distributions of these characteristics for each box.

As already discussed, impacts are to be expected from changes in surface albedo, moisture availability and roughness. GCMs confirm these expectations. They show that if the albedo of the land is decreased, the increase in thermally forced low level convergence and ascent leads to a widespread increase in rainfall over land in the tropics and the summer hemisphere with decreases over adjacent oceans (Figure 1.3). On a smaller scale, Charney demonstrated a similar response when using a GCM to test this hypothesis in the context of the Sahel drought (Figure 1.4). The increase in Sahel albedo was accompanied by a southward shift in vertical velocity and rainfall patterns combined with an increase in maximum precipitation.

The importance of evaporation over land as a moisture source for precipitation on a continental scale has been equally clearly demonstrated in several GCM experi-

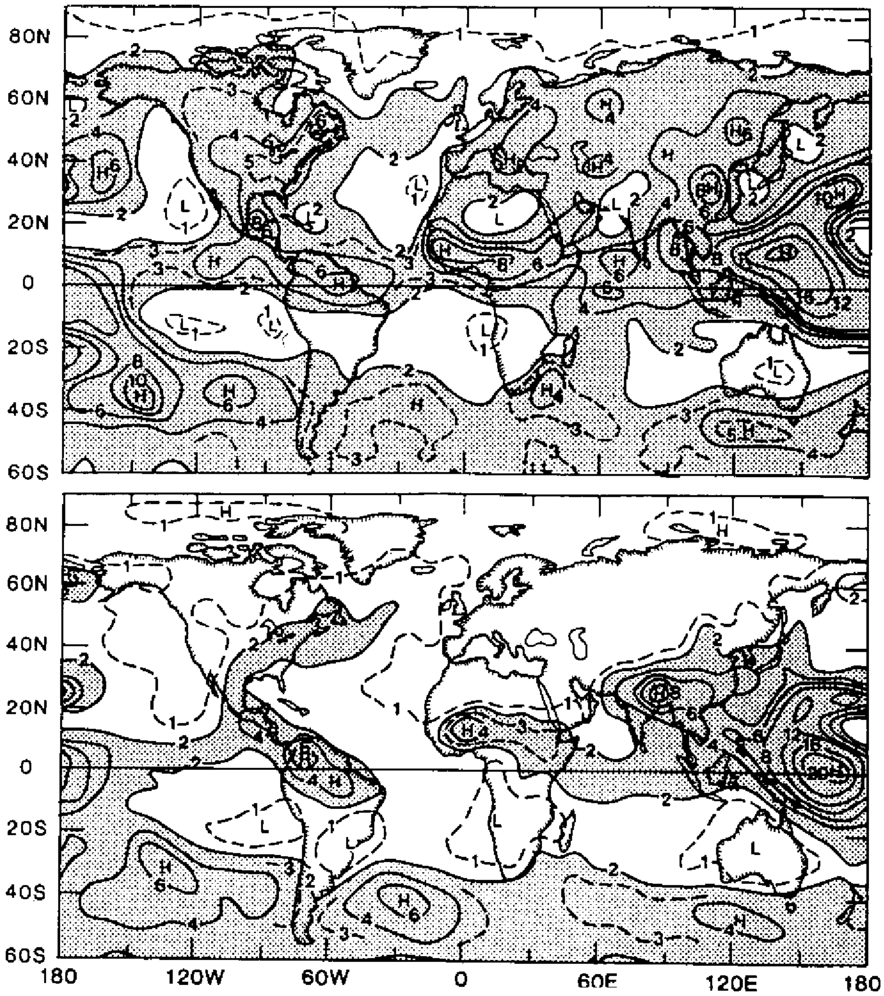

Fig. 1.5 Precipitation (mm/d) in wet-soil case (top) and dry-soil case (bottom). Precipitation greater than 2mm/d shaded (from J. Shukla and Y. Mintz, 1981).

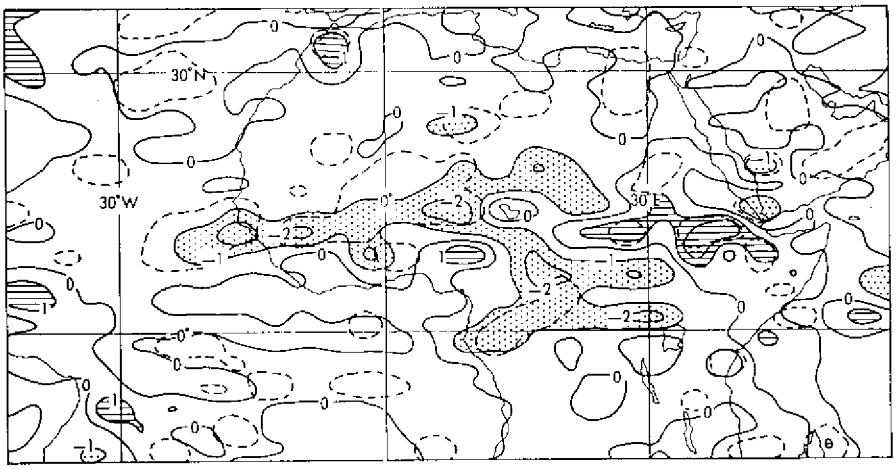

Fig. 1.6 Differences in rainfall (mm/d) for June to August of the experiment with reduced soil water capacity. Contours at 0, 1, 2.5 mm/d with increases (decreases) of over 1 mm/d hatched (stippled) (from P. R.Rowntree and A. B. Sangster, 1986).

ments. Complete elimination of evaporation over land transforms the modelled northern summer rainfall distribution, restricting it to the tropical convergence zones (Figure 1.5). In the same experiment the circulation was changed equally dramatically by the elimination of evaporation, with decreases in sea level pressure of 10 to 20 hPa over much of Eurasia and rises of similar magnitude over the Pacific Ocean. Surface temperature over land in the summer hemisphere were increased by 20 to 30 K in the absence of evaporative cooling.

Again, similar results have been obtained on smaller scales. Restriction of soil moisture storage and hence evaporation over Africa north of 10° N in summer reduced rainfall over the Western Sahel (Figure 1.6). The increases further east can be attributed to intensification of the Saharan heat low due to drying of the surface and the consequent increase in northward advection of moist air on its east side. A similar mechanism may have been responsible for the increased rainfall over northern India in Figure 1.5.

Changes in the physical parameterizations can have similar impacts. Any land-surface changes would probably affect albedo, soil moisture and surface roughness. A reduction in vegetation commonly increases albedo and runoff, while decreasing the soil moisture storage available to the atmosphere through plants. Experiments have shown decreases in rainfall from the combined effects of increasing albedo and reducing soil moisture storage in the context of tropical deforestation and desertification of the Sahel.

In the Sahel experiments, albedo increases, when combined with the moisture storage reductions, tended to weaken the Saharan heat low, opposing the tendency to increase rainfall in the eastern Sahel and leading to a more general decline in rainfall throughout the Sahel. This and the changes to the south — wetter in the west, drier in central Africa — were reminiscent of the observed changes in some recent Sahel drought years.

Reductions in surface roughness such as would accompany development of desert conditions also appear liable to decrease rainfall and so provide a positive feedback. If the roughness over deserts is reduced from values appropriate for wooded savannah to those of a smooth desert, analysis of the results for the Sahara revealed reductions in moisture convergence and rainfall due to reduced frictional convergence into the Saharan heat low.

1.3. The role of models at smaller scales

Global models are constructed to model the large scale pattern of climate and climate changes. They do not provide a resolution in time and space that allows direct application of the results of model computations into the regional scale at which the changes affect mankind, and at which a validation of the satellite data evaluation becomes feasible. It is therefore an essential component of ISLSCP that data are used in conjunction with models which allow accurate modelling of land-surface processes at pixel size. Such studies serve at the same time to improve

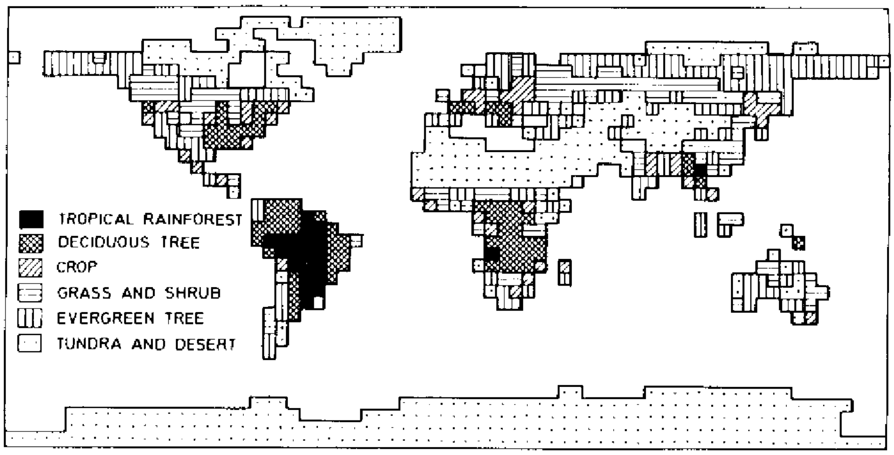

Fig. 1.7 Distributions of major ecotypes ($5^0 \times 5^0$) derived from NOAA normalized vegetation index established from one year's data, May 1982 to April 1983 (from A. Henderson-Sellers et al. 1986).

the evaluation algorithms since the models used to infer the information are in principle very similar to land-surface-atmosphere interaction models except that they are used in an inverted manner.

1.4. What data sets are needed to perform model computations

One final goal of the modellers is, of course, to develop super-models in which all subsystems of the climate system interact in a correct way. Such a model would have to simulate the atmosphere, the complete hydrological cycle, vegetation growth, sand-storms, ocean currents and ice melting. Models with this capability will not be available for some time because of the enormous computer capacity needed. It is therefore necessary to describe in the presently available sub-system models certain boundary conditions by empirical data sets. As far as the land-surface is concerned, the albedo and thermal properties of the surface are likely to be prescribed for some time. Another part of this description is the coverage, type (Figure 1.7) and the state of the vegetation, especially in the large marginal land-use areas of the world. Also modifications due to desertification and changes in land-use must be assessed by observation.

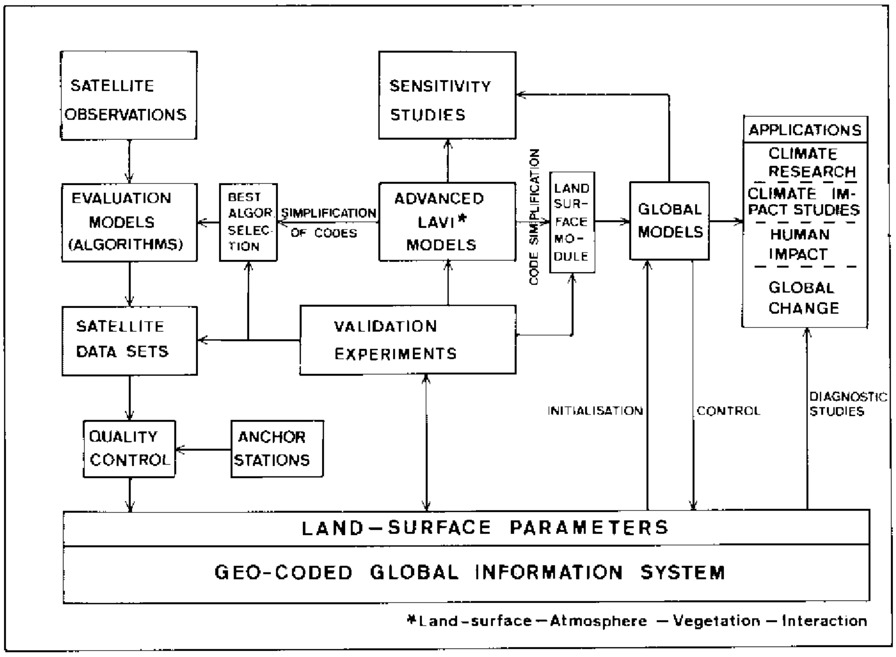

Fig. 1.8 ISLSCP research activities and their interrelation.

1.5. What different data sets are needed to test the performance of the models

Models generate processes internally that cannot easily be checked directly using empirical methods. These are the water vapor and heat transports in the atmosphere, soil moisture variations, exchanges of heat and momentum between the surface and the atmosphere, boundary layer structure and precipitation. However, these processes result in observable quantities like cloud extent, albedoes and emitted radiances, surface temperature and their diurnal amplitudes, changes of surface roughness and soil moisture in the uppermost layer, which are directly accessible by observations but must be averaged according to the geographical grid-size used in the computations.

Models will also continue to improve their algorithms. For this purpose rather detailed multitemporal data sets are necessary for test areas. The quantities that are important in this respect are radiative fluxes, albedo and its spatial variability, vegetation classes and their fractional coverage averaged over the model grid-width, topographical information, temperature variability and soil moisture distributions.

1.6. What can ISLSCP contribute?

1.6.1. The research strategy of ISLSCP

It is generally understood among scientists co-operating in ISLSCP that an assessment of changes in land-surface characteristics that exceeds a purely descriptive analysis by means of satellite pictures must be based upon a profound knowledge of the system that is composed by the soil with its hydrology, the vegetation and the atmosphere. This detailed knowledge can only be achieved by means of models that describe the exchange of energy and matter (primarily in terms of water) as a function of quantities measurable from space like temperatures and spectral characteristics of the surface. From these detailed models there must be derived, on the one hand, simplified "parameterizations" that can be used in global models to simulate the impact of changing land-surface characteristics on the global system, and on the other hand algorithms that can be used to interpret satellite data in terms of land-surface parameters and their changes in time (Figure 1.8). Fields studies are necessary to validate the accuracy of the parameterizations and algorithms. These validation experiments have to be carried out under a variety of climatic conditions in order to get a broad database for quantitative intercomparison with each other and with experimental results. Only on such solid grounds does it then become useful to produce global satellite data sets for studies of climate changes and their impact on the land-surface. In the meantime partial and not completely validated data sets will become available that can be used for preliminary pilot studies to make assessments of the accuracies required in the different fields of application. The merging of these data sets with other data in global geographically organized information systems is then a task that already reaches beyond the scope of ISLSCP. It is expected that the results of ISLSCP will be fully exploited in the design of future space-borne observation systems.

1.6.2. Necessary co-ordinative tasks

In order to achieve the overall scope of the project, the ISLSCP Steering Committee will have to:

- alert satellite operating agencies about the deficiences of present observation systems and assist them in designing instruments that correspond better to future research needs,
- build up a research community that is concerned with the development of algorithms and lays the ground for a broader use of satellite data to study the Earth's renewable resources and climate,
- stimulate the evaluation of satellite data, including retrospective ones, on regional and global scales and to conduct pilot studies with these data assessing the changes that occur either in specific areas or over limited time periods,
- prepare the tools for a later operational production of global data sets,
- co-ordinate the activities necessary to validate the inferred information and to develop a quality control system.

1.7. How ISLSCP operates

ISLSCP depends both on the enthusiasm and the activity of individual scientists and on the sponsorship of international and national research organizations and administrations, which are interested in a more efficient use of data gathered by space platforms.

The early support of ISLSCP by UNEP and other organizations allowed the concerned scientists to build up a structure for communication and co-operation. The form which was chosen for this structure is that of an International Scientific Steering Committee, that oversees the whole project, organizes workshops and meetings, advises field programs and communicates the results of the project to the wider scientific community. Meetings of the Steering Committee are partially financed from international or multinational funds and partially from national contributions, which the members of the Steering Committee obtain from their national sponsoring organizations.

WMO appointed a Project Manager seconded by NASA to co-ordinate the steps necessary for the production of global data sets needed for the WCRP and to keep contact with the agencies which will ultimately be responsible for the operational data production. To support the work of the Steering Committee, to integrate and communicate the information gained around the world and to handle financial matters, the Secretariat has recently been formally established under the auspices of IAMAP at the Free University in Berlin.

This modest organization needs the support from nations whose scientists are co-operating in the ISLSCP. All scientific activities like the evaluation of larger sets of satellite measurements and the fields campaigns needed to validate the inferred data have to be conducted at a national or multinational level. For this purpose national groups or committees have been established. In Europe the participating scientists have formed a working group in the framework of the European Association of Remote Sensing Laboratories (EARSeL) — it is also expected that the Commission of European Communities will respond to a similar proposal. In the U.S.A., NASA has assumed the role of the lead agency but there is also significant involvement in the parts of NSF and NOAA. In order to keep the lines of information and travel to a minimum the establishment of regional ISLSCP sub-structures such as "Sectors" for the Americas, Europe-Africa and Asia are encouraged.

Scientists and organizations who would like to generate national activities in the framework of ISLSCP, may contact the Secretariat or individual members of the Steering Committee for advice. Steering Committee members have already given several presentations on ISLSCP in different continents to promote research in this direction, and they are ready to continue with this as long as the necessary funds can be raised.

It is expected that the national groups operating under ISLSCP will communicate their results back to the Steering Committee so that a general assessment of the value of satellite data becomes possible and a generally accepted and carefully checked set of algorithms can be established for the future operational production of satellite data sets.

It is the final goal of ISLSCP to shift the responsibility for the production of validated data sets over to agencies and major research institutions. It may then concentrate on the quality control of the data and the use of the data to learn more about the „system" Earth.

2. WHAT THE EVALUATION OF SATELLITE MEASUREMENTS TEACHES US PRESENTLY ABOUT LAND-SURFACE CHARACTERISTICS AND THEIR VARIABILITY IN SPACE AND TIME

2.1. How reliable are present satellite data interpretations?

Data are presently produced by operational meteorological satellites, semi-operational land-observation satellites and experimental systems (Table 2.1). They consist of images as well as information about the vertical structure of the atmosphere. In the future more and more microwave data will also become available. The evaluation of these data is in most cases not a straightforward matter as we shall see later, and there are different possible approaches to infer the desired information. The application of different algorithms may also result in slightly different products. The user of data derived from satellite measurements ought therefore to be acquainted with the method used in the derivation of the data in order to judge their applicability to specific problems.

The reliability of information derived from satellite measurements unfortunately does not only depend on the computer software applied to them. The behaviour of the instruments in space also affects the quality of the output. Though the record of most sensors is excellent as far as sensitivity, length of operation time and signal quality are concerned, most applications for climate research require very high accuracies which can only be assured if the calibration of the sensors and the intercalibration between sensors on board of different satellites is accurately controlled. Measures have been taken to improve the situation in this respect but at present a number of instruments have still to be calibrated by comparison with simultaneous surface observations. Intercomparative measurements at the surface are also still needed to validate the information derived from the satellite measurements.

Much progress has been made during recent years in understanding the problems involved in high accuracy data evaluation, and many efforts have been initiated under the ISLSCP to solve them. Nevertheless, much work has still to be done before satellite data products can be distributed with the same confidence as conventional data. It must, however, be realized that also the development of more sophisticated conventional observation systems was a long task and that there are still efforts under way to improve some of their components.

2.2. The surface albedo and the solar global flux at the surface of the Earth

The ratio of the solar radiative flux that is reflected from a surface to the flux intercepted by the surface is called albedo. Its difference from one determines the

Table 2.1. Present and Future Earth Observation Capabilities from Space.

Type of Space Platform	Instrument/Channels/Spectral Range	Horizontal Resolution km	Repetition Rate of Observation	Status
Geosynchronous Satellites (GOES, GMS, METEOSAT)	VISSR, MSR/2-3/0.5-1.1, (5-7), 10-12μm	0.75-9	15-30 min	operational
	VAS/12/0.63, 3.9-14.7μm	7-14		
Next Generation	more spectral channels, eventually microwave sensors	1-2	15-30 min	from mid 90's on
NOAA Polar Orbiters	AVHRR/5/0.58-12.5μm	1	12 h	operational
	HIRS/20/mostly thermal IR	17.4		
	MSU/4/50.3-57.9 GHz	109		
	AMSU/20/10-90 (180) GHz	50		
	ACZCS/9/0.4-0.9, 10.5-12.5μm	1		
LANDSAT	MSS/5/0.5-12.6μm	0.08	16 d	operating
	TM/7/0.45-12.5μm	0.03/0.1		
DMSP	OLS/2/0.4-1.1, 10.4-12.4μm	0.6	12 h	operational
SPOT	SPOT/4/0.5-0.9μm	0.02/0.01	2.5 d	operating
MOS - 1	MESSR/4/0.51-1.1μm	0.05	17 d	operating
	VTIR/4/0.5 - 12.5μm	0.9-2.7		
	MSR/2/23.8, 31.4 GHz	32/23		
ERS - 1	AMI:SAR/1/5.3 GHz	0.03	undefined	1989
	ASTR/3/3.7, 11, 12μm	1		
Polar Platforms	MODIS/25/0.58-2.13μm	0.5	2 d	from the late 90's on
	HIRIS/7/3.75-12.0μm			
	HMMR/27/1.4 - 183 GHz			
	Possibly additional instruments			

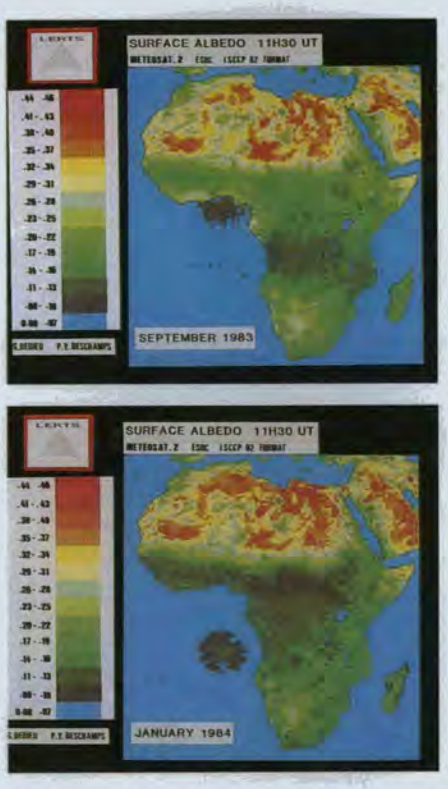

Fig. 2.1 Surface albedo of Africa for September 1983 and January 1984 (after G. Dedieu, P. Y. Deschamps and Raberanto, see Rasool, 1987).

fraction of solar energy that is absorbed by the surface. The albedo is therefore a fundamental quantity for all land-surface processes initiated by solar energy.

Although the parameter entering in climate studies is the albedo, the quantity which is most commonly derived from satellite measurements is the spectral bidirectional reflectance (BDR) for the particular angles of insolation and of observation corresponding to the type of satellite and the time of acquisition. This BDR can be used as an indication or an "index" for temporal and spatial variability of albedo. For example, the BDR over Africa inferred from the visible channel of METEOSAT, is shown in Figure 2.1. From these data a transect of the BDR from South to North Africa, across the Sahelian region and its time variation is shown in Figure 2.2. One notices from these results the very interesting variations with time and space of the BDR.

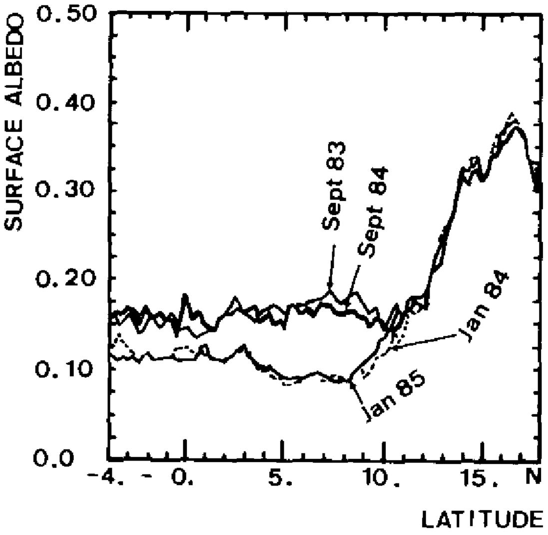

Fig. 2.2 Transect of the BDR across Africa, longitude 20° E.

Variations in time and space are also observed for the global irradiance at the surface in the short and long wavelengths. The values derived from satellite radiances have been compared with those obtained from pyranometers. The results are shown in Figures 2.3 to 2.5. Hourly irradiance values show large differences, partly due to the fact that pyranometers yield local values of insolation while satellites give values integrated over large areas. The daily averaged values are closer, and the monthly averaged much closer to each other, since the time integration smoothes out the variability observed at one location, if it is of a statistical nature.

Albedo maps have already been compiled on the basis of *in-situ* measurements from individual sites for different types of surfaces combined with land-cover data derived from atlases. Figure 2.6 shows the comparison of an albedo map obtained in this manner (a) with a map of satellite-observed surface albedo (b).

2.3. The temperature of the "skin" of the Earth

A meaningful surface temperature of the Earth is difficult to define for a heterogeneous terrain at pixel size. Therefore, up to now, only "brightness" surface temperatures which are well defined at any scale have been determined from satellite. In order to obtain this "skin" temperature, it is necessary to correct for atmospheric effects. Several approaches are again used, either by solving and

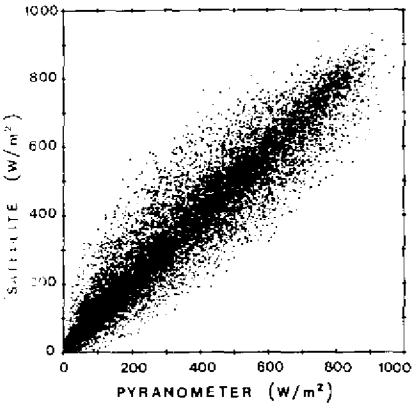

Fig. 2.3
Hourly insolation scatter plot of satellite estimates versus pyranometer measurements (from J. G. Buriez et al., 1986).

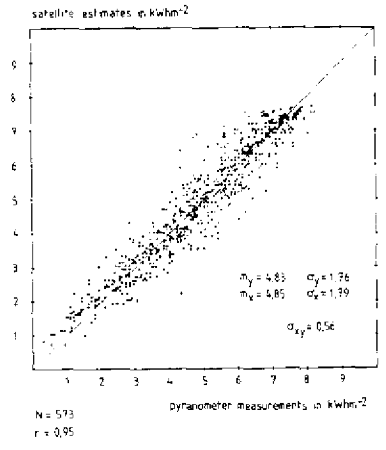

Fig. 2.4
Daily sums of satellite estimates of global radiation compared with pyranometer measurements (from E. Raschke et al., 1982).

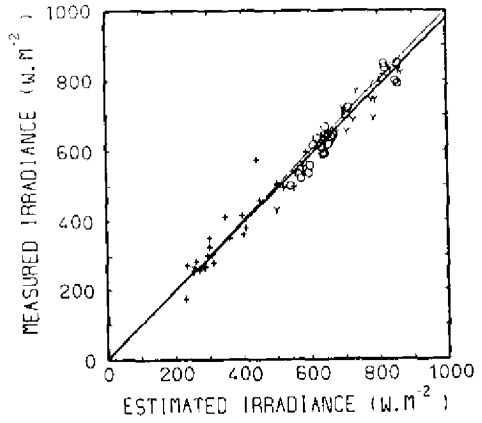

Fig. 2.5
Monthly averages of the mean incident solar radiation — satellite estimates versus pyranometer measurements for March (+), May (O), July (Y) (from G. Dedieu et al., 1987).

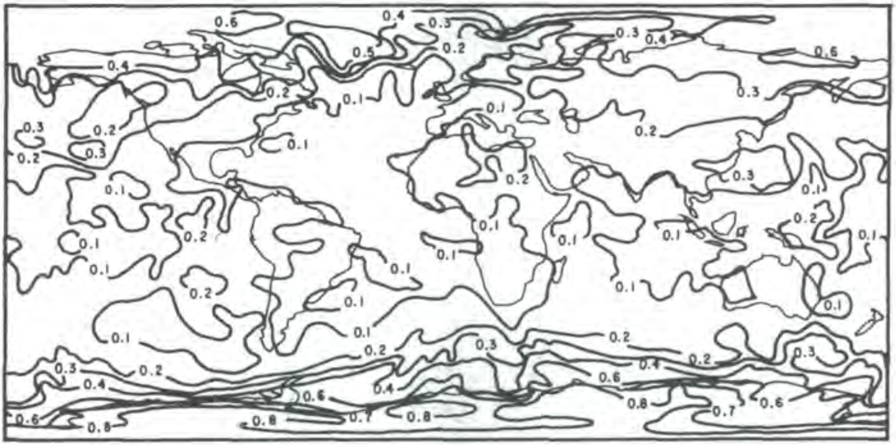

Fig. 2.6 a Surface albedo values from satellite observed minimum albedoes by inversion (after H. J. Preuss and J. F. Geleyn, 1980).

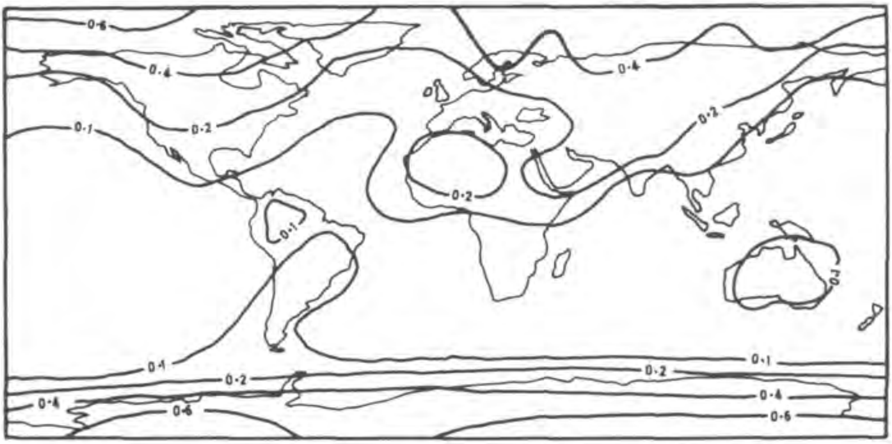

Fig. 2.6 b Surface albedo map drawn from annual average surface albedo values of Hummel and Reck (1979) (from A. Henderson-Sellers and N. A. Hughes, 1982).

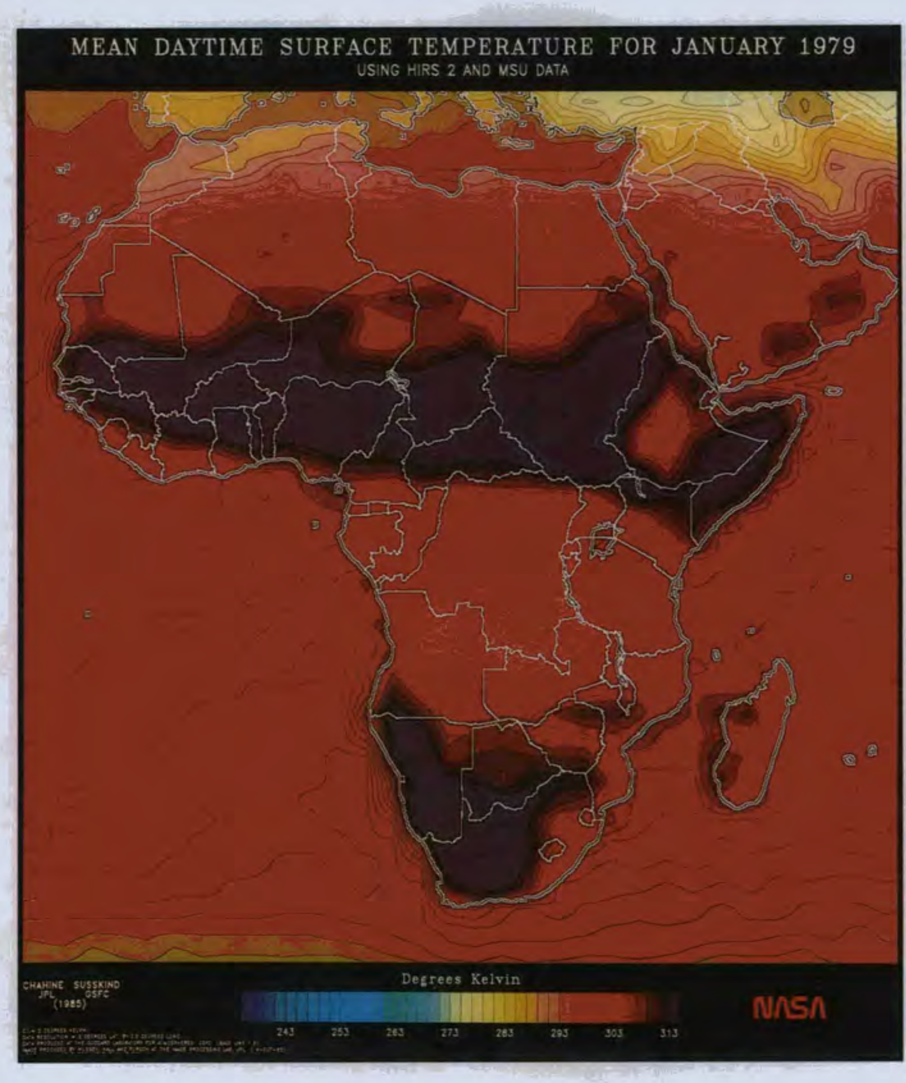

Fig. 2.7 Mean daytime surface temperature for January 1979 (by courtesy of M. T. Chahine and J. Susskind).

inverting the radiative transfer equation using the data of HIRS 2 and MSU of TOVS on board of the NOAA/TIROS satellites or the so-called split-window method applicable for the Advanced Very High Resolution Radiometers

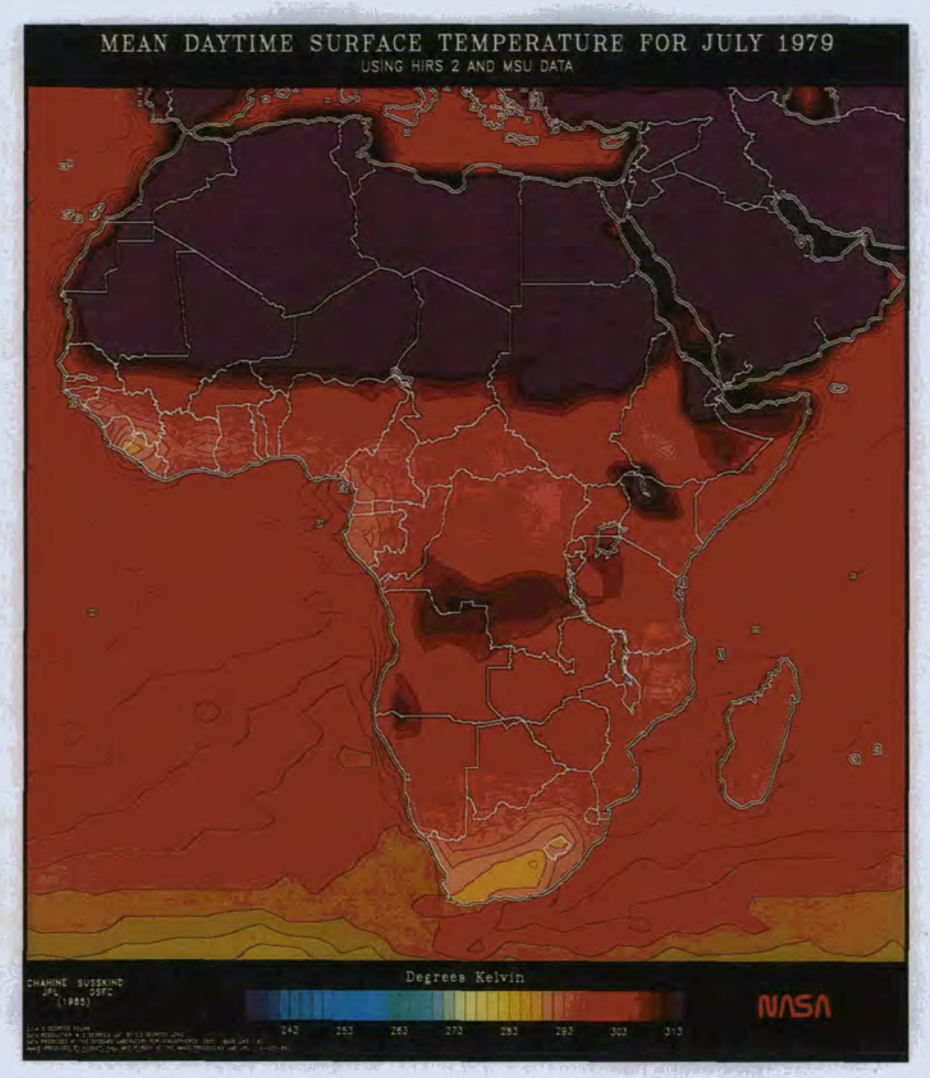

Fig. 2.8 Mean daytime surface temperature for July 1979 (by courtesy of M. T.Chahine and J. Susskind).

(AVHRR) or the angular differential absorption method. Several maps of skin temperature have been published. Some examples over Africa are shown in Figures 2.7 and 2.8.

The seasonal and annual variations of the skin temperature are readily observable from these images and can be compared with the variation of albedos during the same period.

Unfortunately, these skin temperatures are not directly usable for determining heat fluxes which are related to the thermodynamic surface temperature. The relationship between skin temperature and thermodynamic surface temperature, T_s, depends on the emissivity ε of the surface and the longwave atmospheric downward radiance R_a. For a given brightness temperature we may write

$$\frac{\Delta T_s}{T_s} \simeq \frac{1}{4} \frac{\Delta \epsilon}{\epsilon} \left(1 - \frac{R_a}{\sigma T_s^{\ 4}}\right)$$

Over deserts, the error ΔT_s of this surface temperature due to an error in the emissivity $\Delta \varepsilon$ may be of the order of $\Delta T_s \approx 44 \Delta \varepsilon/\varepsilon$ and about half this value over grassland in summer. A knowledge of the emissivity within 0.2 % is therefore necessary. Unfortunately, methods are not available to obtain the emissivity from space with such an accuracy. Nevertheless, work is in progress as part of ISLSCP and some results over various types of soils have shown large variations of ε, but fortunately very small variations with the angle of observation.

Nevertheless, the variation of observed emissivities shows that errors of several Kelvin may result in the determination of land-surface temperature for clear sky conditions.

2.4. Relations between albedo and surface temperature

Despite the preliminary character of these first results, they already show interesting features concerning the possible mechanisms of regulation of the surface temperature. Three of them are in competition:

- The radiative regulation: when the albedo increases, the energy absorbed by the Earth's surface decreases leading to a decrease of the surface temperature.
- The evapotranspiration regulation: when the albedo increases, this is often due to a reduction of the vegetation, therefore a reduction of the evapotranspiration rate. This leads to an increase of the surface temperature.
- The aerodynamic regulation: when the density of small and sparse vegetation decreases, the surface becomes smoother. This hinders the transport of heat and moisture away from the surface by turbulent eddies and leads to an increase in surface temperature during the midday hours. If, however, a closed canopy of trees is thinned out, the opposite occurs.

A south-north transect over Africa across the Sahelian region illustrates this behaviour (Figure 2.9). In the south predominates a regulation by evapotranspiration and turbulent transfer, while in the north this regulation is principally due to the radiation flux.

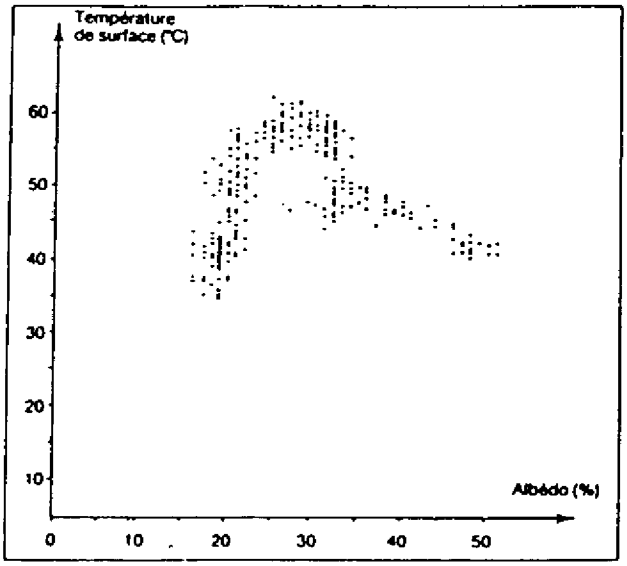

Fig. 2.9 Relationship between surface albedo and temperature along a south-north transect through Senegal with METEOSAT-6 July 1979 (from B. Seguin et al., 1987).

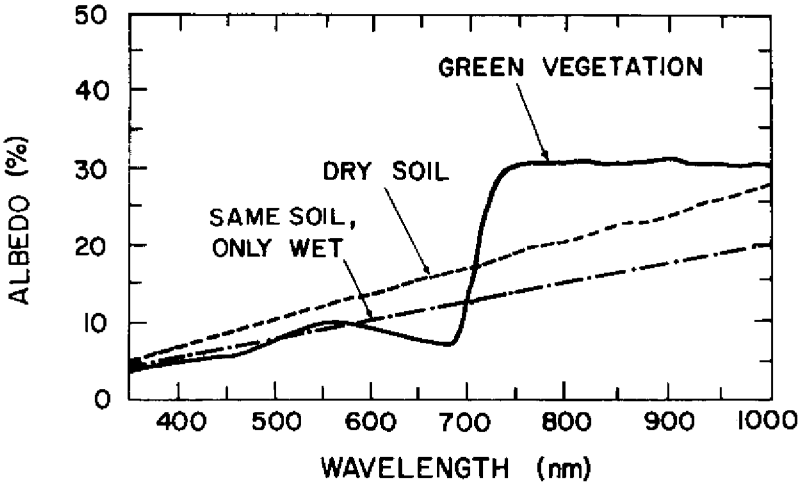

Fig. 2.10 Spectral reflectance of vegetation, dry and wet soil (from C. J. Tucker and L. D. Miller, 1977).

2.5. Vegetation: An indicator for the availability of water

The spectral reflectance of vegetation is markedly different from that of most soil materials (Figure 2.10). It is determined by the absorption of chlorophyll at blue and red wavelengths. In the near infrared the radiation is scattered by leaves or needles. This results in generally high reflection which depends mainly on the geometry and size of the leaves or needles. By contrast, vegetation reflectance is low in the visible region (400—700 nm) with a small secondary maximum around 550 nm.

When vegetation is stressed by shortage of water, and also at the end of the growth period, the chlorophyll absorption weakens and the ratio of near infrared to red or visible reflectance decreases. This ratio, called vegetation index (VI), is therefore a measure for the physiological activity of the plants. In practice, the normalized difference vegetation index (NDVI) is often used to characterize the state of vegetation. This is the difference between NIR and VIS reflectance divided by their sum. Either quantity can be easily calculated from satellite measurements. Figure 2.11 gives three examples of the variability of the NDVI over Europe. The upper two scenes demonstrate the interannual variability between a dry year in northern Europe and a "normal" year. Stress induced by water shortage results in a reduction of the magnitude of the vegetation index. The lowest scene shows the difference between a summer month and a spring month. There are sound theories supported by a number of experiments that this index is related to the biomass production integrated from the beginning of the growing season to the time of the measurements, provided that this span is not longer than the vegetation period (Figure 2.12).

The NDVI is difficult to interprete in cases of sparse vegetation because also the reflectance of most soils increases slightly with wavelength (Figure 2.10). In order to discriminate between sparsely vegetated and bare soil therefore additional information has to be used. One way to obtain such additional information is by correlating the NDVI with the reflectance in the red spectral region. If this reflectance is relatively low there is high probability for vegetation with chlorophyll absorption. Also the sign or slope of the cross-correlation between the NDVI and the red reflectance is a good indicator for the presence of vegetation (Figure 2.13).

Figure 2.14 is from an area in Niger, east of the town of Tahoua. The upper scene shows the difference of the vegetation index between a wet and a dry period. Open water in the wet case that is dried out in the dry year is indicated by dark blue colors in the difference image. Red indicates the distribution of vegetation and by this of soil moisture in the wet year. The blue tone in fact indicates that the vegetation index was larger in the dry than in the wet year. The reason for this is demonstrated in the lower part of the figure: under dry conditions the vegetation (red color) invaded the former water ponds thus indicating that there was still enough soil moisture in lower layers available to let the plants grow. The qualitative results

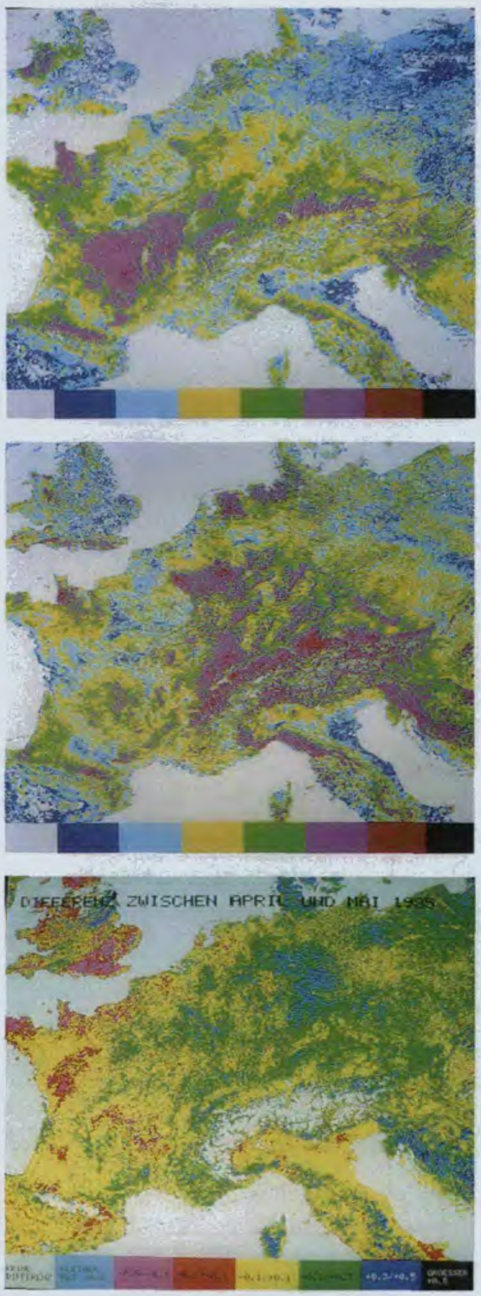

Fig. 2.11
NDVI over Europe for the "dry" September 1983 (a), the "normal" September 1985 (b) and difference between May and April 1985 (c). The colour coding for (a) and (b) ranges from blue (no vegetation) to red (maximum NDVI). In (c) green and blue indicate an increase, cyan and magenta a decrease of the NDVI from April to May.

obtained so far will have to be quantified in the future when observations at the ground become available.

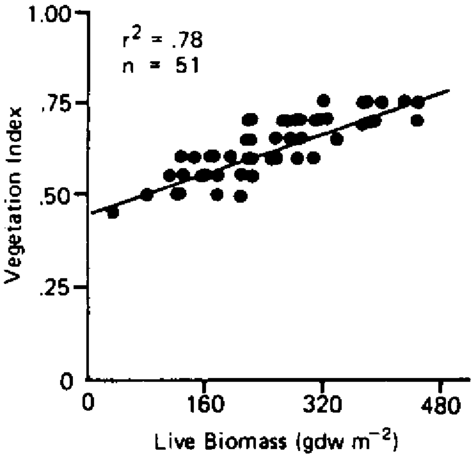

Fig. 2.12
Relationship between NDVI from LANDSAT-TM and live biomass for graminaceous plants (Spartina alterni flora) (from M. A. Hardisky et al., 1986).

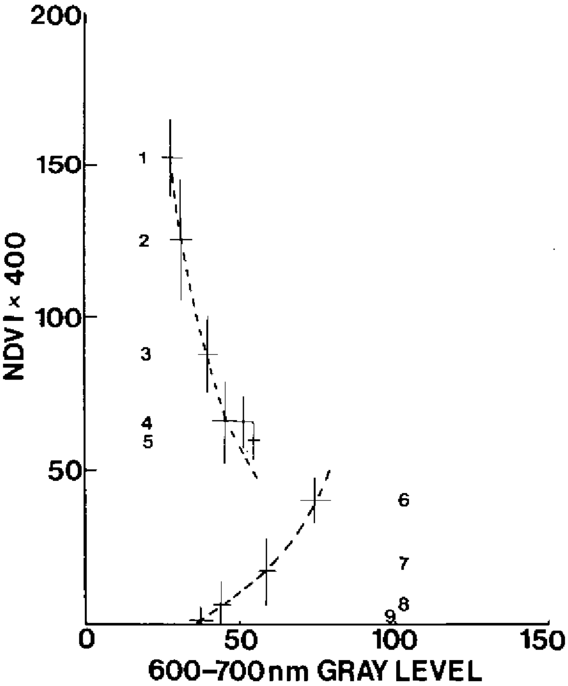

Fig. 2.13
Classes of vegetation (1—5) and bare soil (6—9) derived for the area of Figure 2.14 by correlating the NDVI and the radiance received in band 2. Sparse vegetation can be distinguished from bare soil by the covariance between NDVI and the reflectance in the red spectral band.

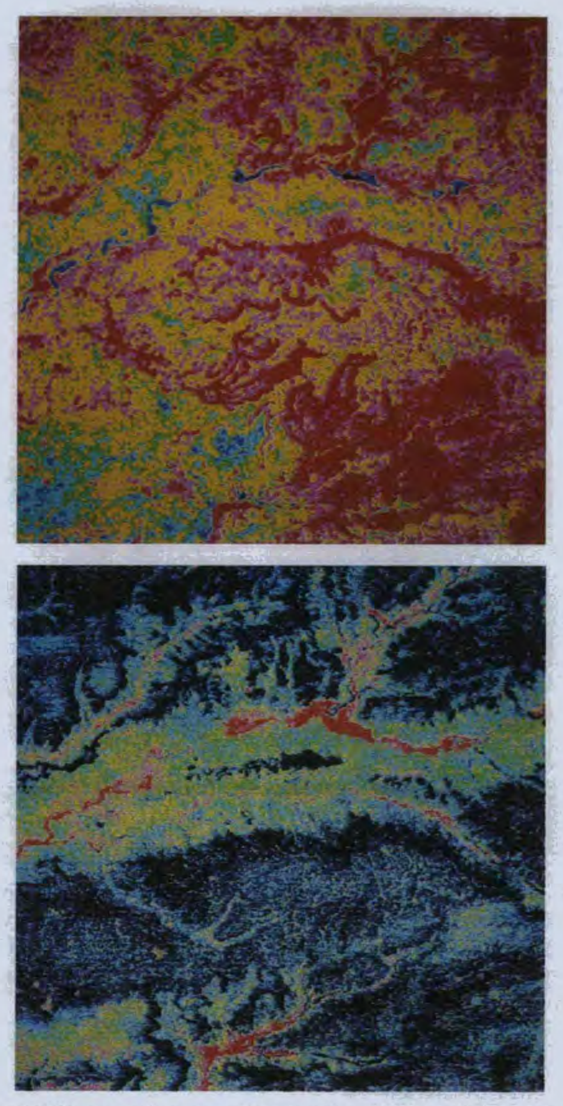

Fig. 2.14 Top: Difference between November 1972 and August 1978 of NDVI derived from LANDSAT MSS east of Tahoua, Niger. Red colors indicate higher NDVI in 1972, blue colors higher NDVI in 1978 (yellow is neutral). NDVI averaged over 3 × 3 pixels. Bottom: NDVI LANDSAT MSS scene on January 31, 1976, east of Tahoua, Niger. Red color stands for vegetation ($NDVI = 0.4$), green, yellow and blue colors for different kinds of bare soil with non-zero NDVI.

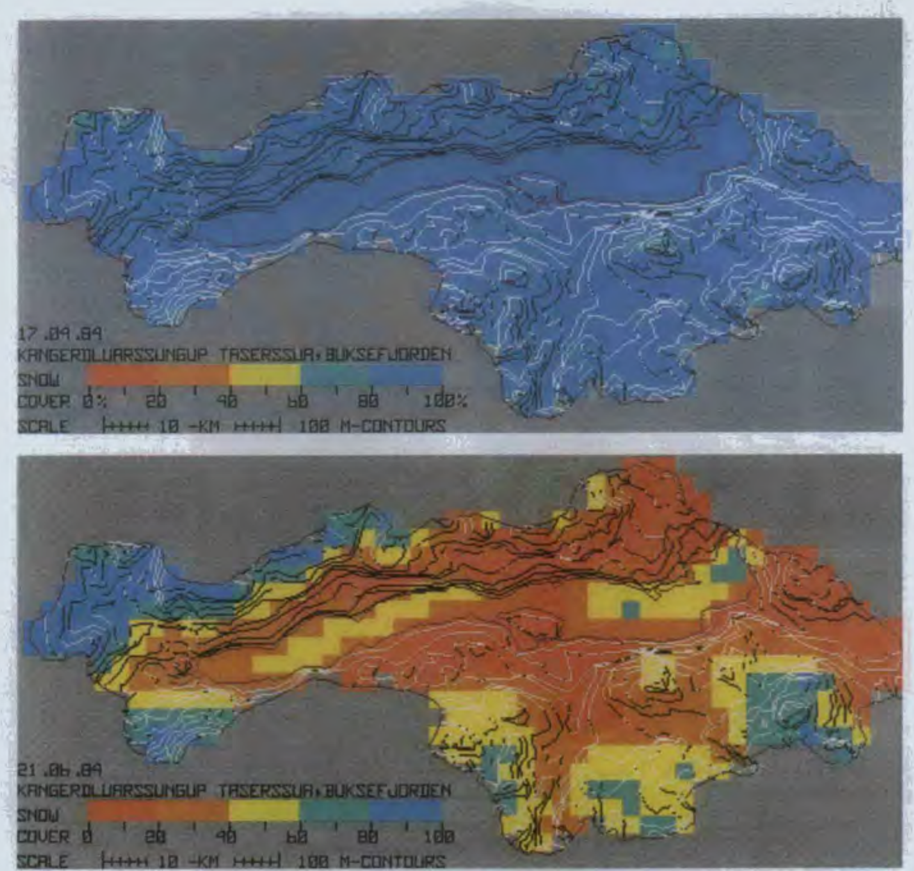

Fig. 2.15 The geographical distribution of the snow cover in the Kangerdluarssungup Tasersua-basin near Nuuk, Greenland, on April 17, and June 21, 1984. By use of the relationship indicated in Fig. 2.17 the amount of meltwater generated up to June 21, can be estimated to 300 mm of water (from H. Soegaard, 1986).

2.6. Hydrological quantities

Hydrological quantities are important for energy transfer processes in the atmosphere and at the ground. Rain and the soil moisture affect the growth of vegetation and feedback via the albedo to the radiation budget and via transpiration to atmospheric humidity. The snow cover and in particular its seasonal variations have also a direct influence on the albedo and the radiation budget as well as it effects the growth of vegetation, soil moisture, run-off pattern and water balance.

Precipitation is currently estimated from cloud structure and cloud top temperature. In the case of convective clouds also the growth of the area covered by the cirrus screen combined with its effective emission temperature is used to localize precipitation cells and to estimate the amount of rain. Frontal precipitation is more difficult to assess because the development is less explosive. But in this case a combination of satellite data with meteorological information such as advection of vorticity in the upper troposphere, a measure of vertical motion, provides reasonable results. Another use of satellites for precipitation measurements is their capability of relaying messages from automatic stations to a central ground station. A network of rain gauges with automatic data collecting systems exists around the river Niger, from which the data are transmitted via METEOSAT to Toulouse.

The amount of precipitation deposited as snow can in global studies be estimated from microwave data (see Figure 6.3). On a local scale NOAA-AVHRR data have been applied for mapping of snow cover (Figure 2.15) and snow structure (Figure 2.16) and indirectly the water equivalent can be derived from the same data as shown in Figure 2.17.

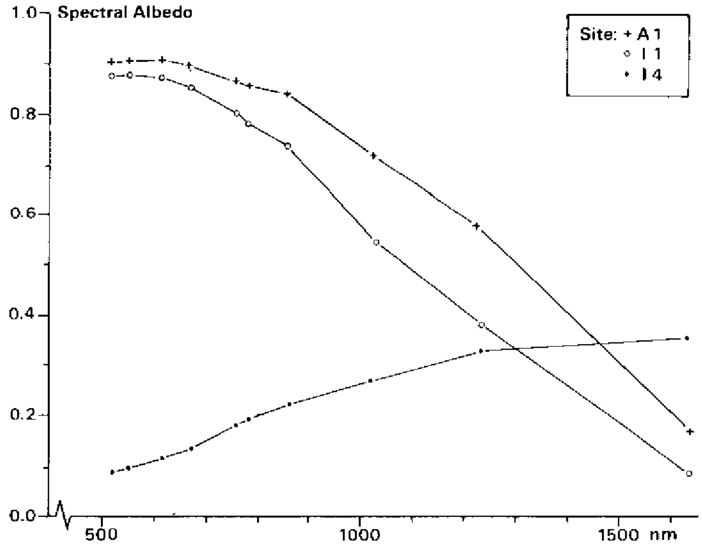

Fig. 2.16 In situ observations in Greenland of spectral signature over three typical surfaces in the arctic /subarctic environment. (+): dry frozen snow, (o): wet snow at melting point, and (·): arctic vegetation of grass, mosses and willow. The three surfaces are easily distinguishable by multitemporal analysis (from H. Rott and H. Soegaard, 1987).

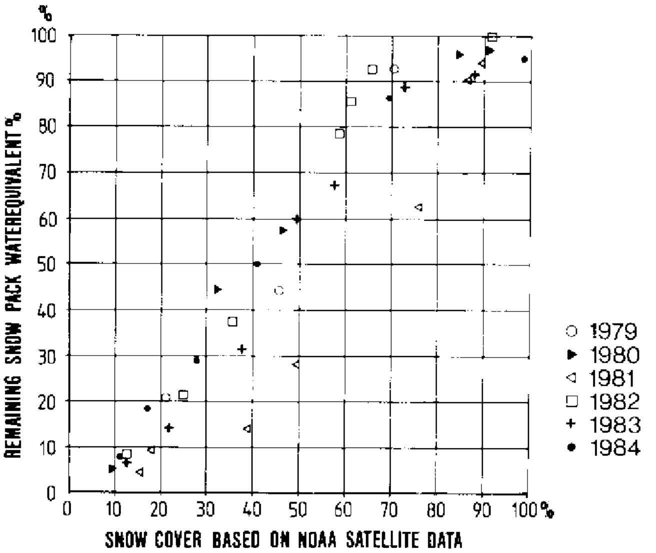

Fig. 2.17 Relationship between snow cover estimated from satellite data and remaining snowpack water equivalent in the Kangerdluarssungup Tasersua-basin near Nuuk, Greenland. Only the data from 1981, NOAA-6, show inconsistency, which is due to the low sun angles in connection with these data (from H. Soegaard, 1986).

To assess soil moisture is more difficult since most information picked up by space borne instruments is limited to the uppermost layer of the bare soil. The albedo of most soils changes if they become wet, and also their diurnal temperature amplitude is reduced, but the interpretation of these effects is difficult for inhomogeneous terrain and not applicable for vegetated surfaces. Microwaves penetrate a few centimeters into non-vegetated soils and the return signal is affected by the amount of moisture in this layer, but each soil reacts individually. To date no algorithms exist to extract information on soil moisture globally from microwave data, although some preliminary studies combining microwave with thermal infrared data are already very encouraging.

Soil moisture at lower levels, if covered by a dry layer, cannot be detected directly. However, vegetation can be used as an indicator of the availability of water in the root zone.

Other indicators of the availability of water are open water ponds and the variability of their size with time. Studies of this kind have been made e.g. for Lake Chad (see Figure 2.26). They require the high resolution data of the LANDSAT MSS and TM, SPOT or MOS-1 type.

2.7. Heat fluxes

The simplest method to infer heat fluxes from radiances measured from space is based on a linear relationship between the daily evapotranspiration $\overline{LE}$ and the difference $(T_s - T_a)$ of the maxima of the surface brightness temperature T_s and the air temperature T_a at 2 m as given by a regular meteorological station:

$$\overline{LE} = \overline{R}_N - a\,(T_s - T_a) + b$$

where $\overline{R}_N$ is the daily net radiation flux and a and b are constants. At a given point, this relationship may be very crude (due to the large variability of the wind and the surface roughness), but it is expected to be realistic at climatological scales. This relationship was applied in the south-east of France with the brightness temperature from NOAA/AVHRR; the result is shown in Figure 2.18. Although the results cannot yet be considered as quantitative for each pixel, the general space and time variations shown in this figure display interesting features.

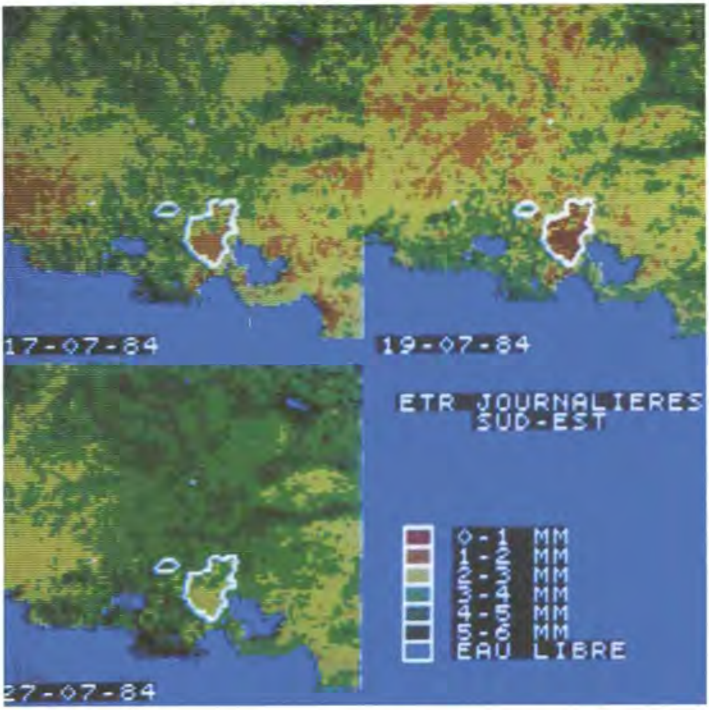

Fig. 2.18 Daily evapotranspiration over the South-East of France in July 1984 (from A. Vidal et al., 1987).

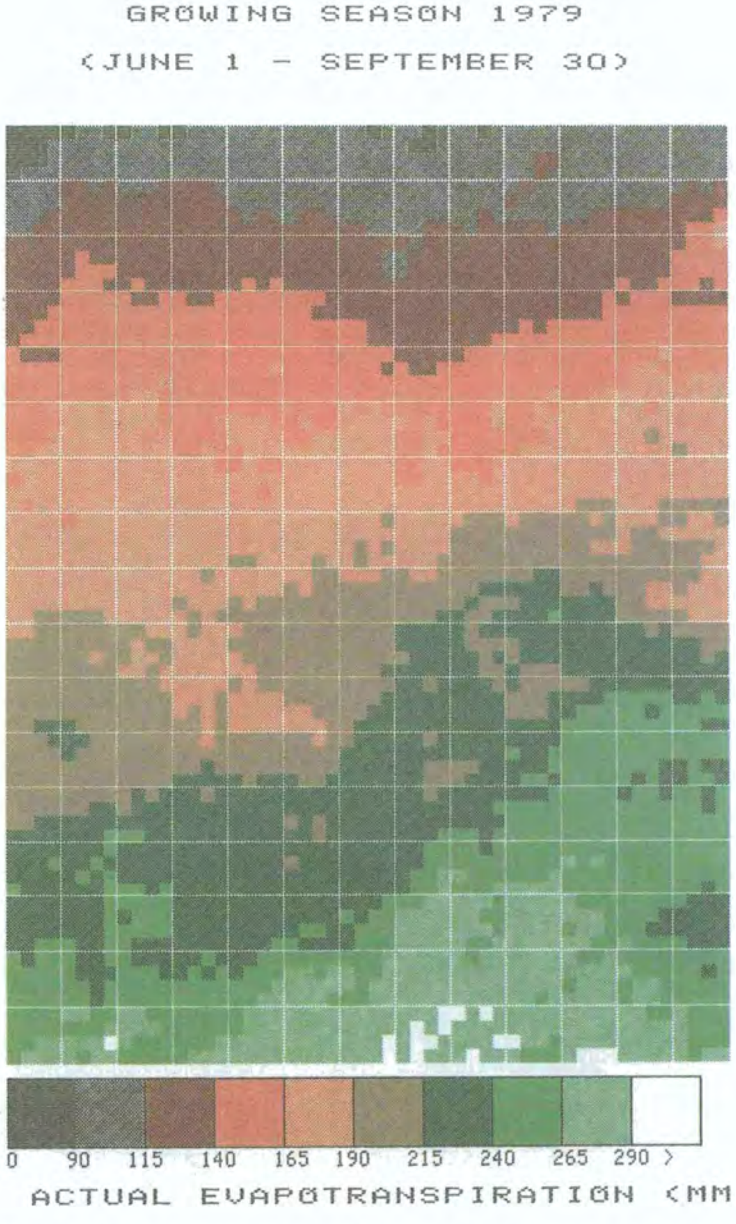

Fig. 2.19 Total evapotranspiration at the end of the growing season over Mali (from A. Rosema, 1986).

The same type of algorithm has been used in the GAMP project to calculate the evapotranspiration rate over Mali at the end of the growing season, as shown in Figure 2.19.

As yet, there have not been direct tests of these inferred flux fields. Independent calculations of the evaporation fluxes over the same area in France yielded results which agreed to 50 % with the previous ones. This gives the order of magnitude of uncertainty obtained to date and which has still to be improved. One should notice again, that these results are strongly dependent on the accuracy of the determination of the surface temperature and on the incident solar global flux.

Since the evapotranspiration depends both on the albedo and the surface temperature, the spatial variations of evapotranspiration LE can be related to the variations of albedo a and surface temperature T_s through a linear relationship

$$\Delta\overline{LE} = \alpha + \beta\Delta a + \gamma\cdot\Delta T_s$$

where α, β and γ are coefficients valid over regions with the same climatic conditions. A typical example of the spatial variation of evapotranspiration obtained over the Libyan desert is shown in Figure 2.20. The cross section correctly accounts for negligible evaporation in the dunes in the Idehan Awbari, and the rocks of the Qarqaf highland. It further depicts a decrease in evaporation going from the wetter southern boundary to the drier northern boundary of the playas.

To be precise, when determining the evapotranspiration fluxes, the differences between the mechanisms of evaporation from bare soil and that of evapotranspiration from vegetated areas must be taken into account. For this purpose a simple

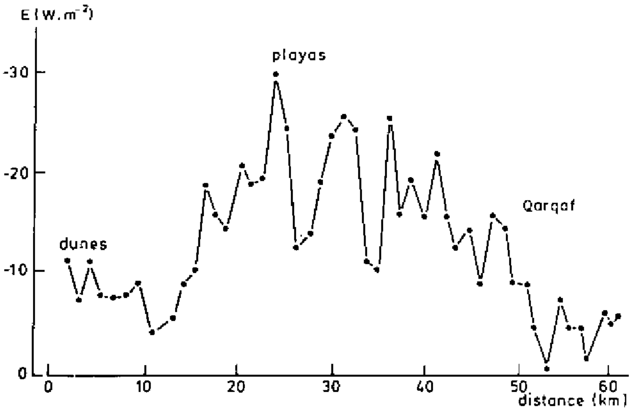

Fig. 2.20 Cross section of the mean latent heat flux ($\overline{LE}$) as calculated by combining satellite and ground reference measurements (from M. Menenti, 1984).

model derived from the FAO radiation model may be adequate. The maximum daily evapotranspiration for a given type of plant is written in such a way as to separate the effects of climatological factors and of crops. It is given by

$$ET_m = k_c ET_o$$

where ET_0, the maximum daily evapotranspiration of the reference (green grass) represents the influence of the climatology factors and k_c is the crop correction factor. The influence of the type of crop on the monthly ET_m is shown in Figure 2.21, resulting in a large variability of ET_m under the same climatological conditions. This figure shows also that the coefficient k_c is not a constant over the year. The seasonal effect is partly due to the variations of the leaf area index.

Other quantities may be derived from satellites, such as the thermal inertia or ground fluxes. But no validated maps of these quantities have yet been produced.

2.8. Microwave radiation and vegetation

Microwave radiation of the Earth as detected by the Scanning Multichannel Microwave Radiometer (SMMR) sensor on board of NIMBUS 7 is influenced by the structure of the vegetation of the surface. The vegetation induces strong depolarization at 37 GHz frequency. For example, the difference of vertically and horizontally polarized brightness temperature at the 37 GHz frequency is about 25K for dry bare soils, while this difference is 5K or less over short crops (alfalfa, for example). Consequently, the 37 GHz data from the SMMR are processed to establish whether these data can be used to quantify the temporal changes in

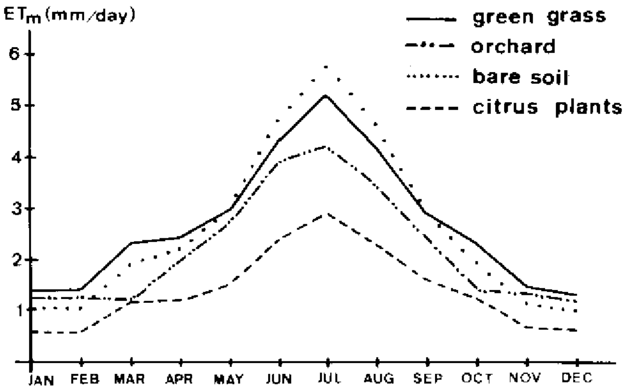

Fig. 2.21 Annual variation of the monthly maximum evapotranspiration in the Valencia region for different crops (from V. Caselles and J. Delegido, in press).

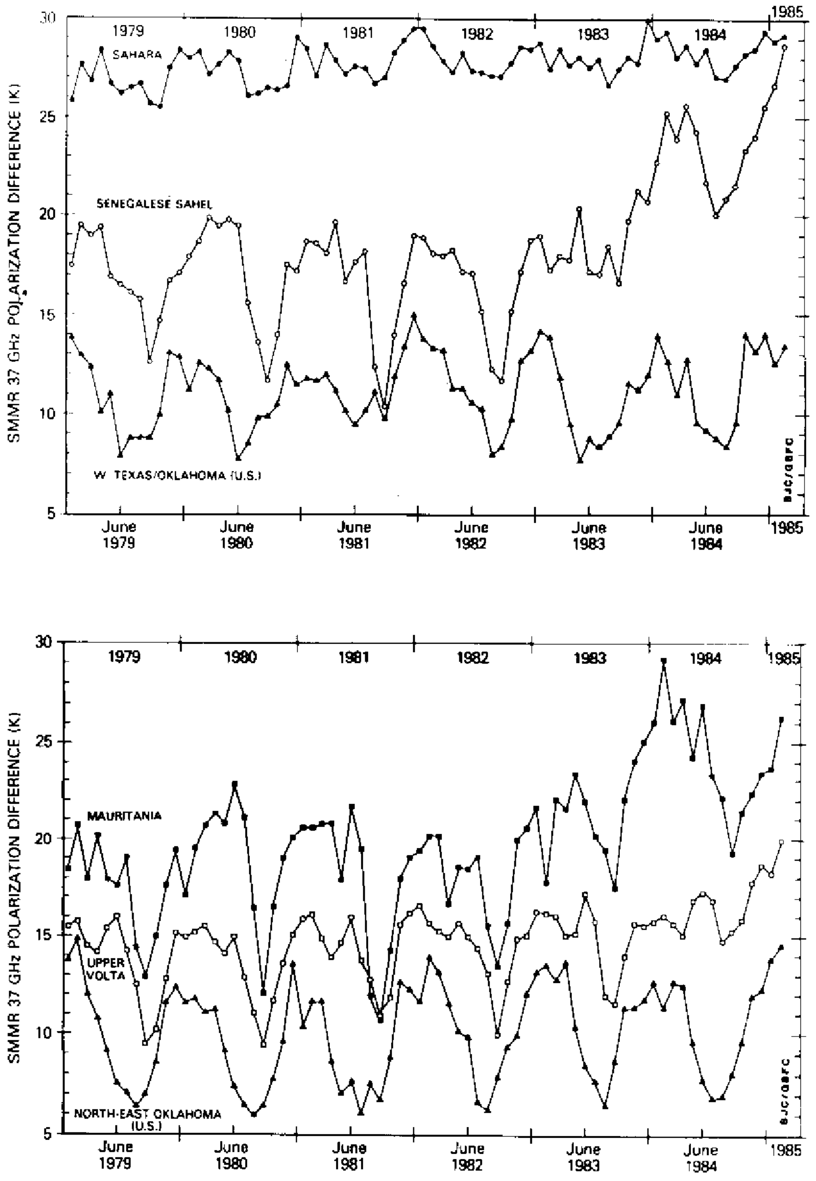

Fig. 2.22 Differences of vertically and horizontally polarized brightness temperatures for North Africa and U.S.A. (from B. J. Choudhury and C. J.Tucker, 1987).

vegetation even under cloudy conditions. First, the weekly SMMR observations for a particular location were screened for the effects of cloud and rain on the brightness temperature by choosing the data for one week out of the four to represent a particular month.

The time series of the differences of vertically and horizontally polarized brightness temperatures for four locations in North Africa and two locations in southern U.S. Great Plains are shown in Figure 2.22 for January 1979 to February 1985. Fig. 2.23 shows the relationship between this temperature difference and the normalized difference vegetation index derived from NOAA 7 AVHRR data from April 1982 to January 1985. A roughly sinusoidal pattern in the time series (Figure 2.22) shows the vegetation growth and decay called the green wave and the yellow/brown wave. The major drought in Senegal since 1983 appears dramatically where the vegetation induced minimum is weakened and the situation evolves toward a similarity with the Sahara. While these results are encouraging, they must be considered preliminary and require validation by ground truth observations.

Figure 2.24 is a color-coded global image of the temperature difference (labelled as the microwave vegetation index), which is an average of monthly temperature differences from April 1979 to September 1985. Validation of these observations is currently being done using the ground truth data from several locations within North Africa.

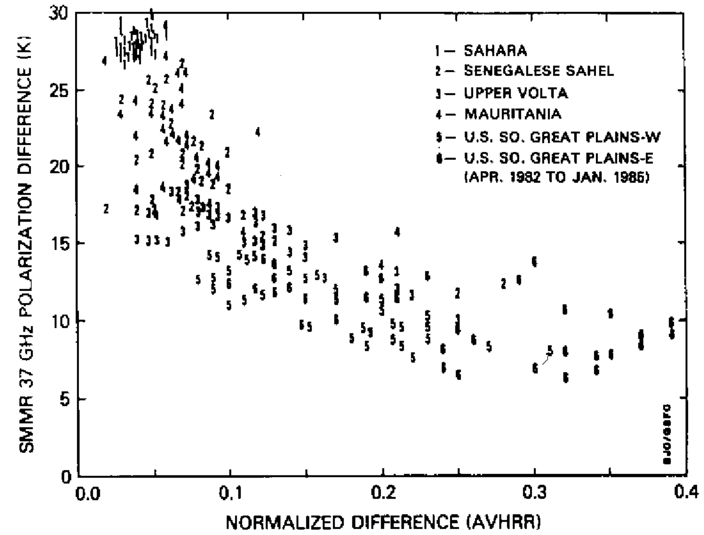

Fig. 2.23 Relationship between the vertically and horizontally polarized brightness temperature and the normalized difference vegetation index (NOAA 7- AVHRR) (from B. J. Choudhury and C. J. Tucker, 1987).

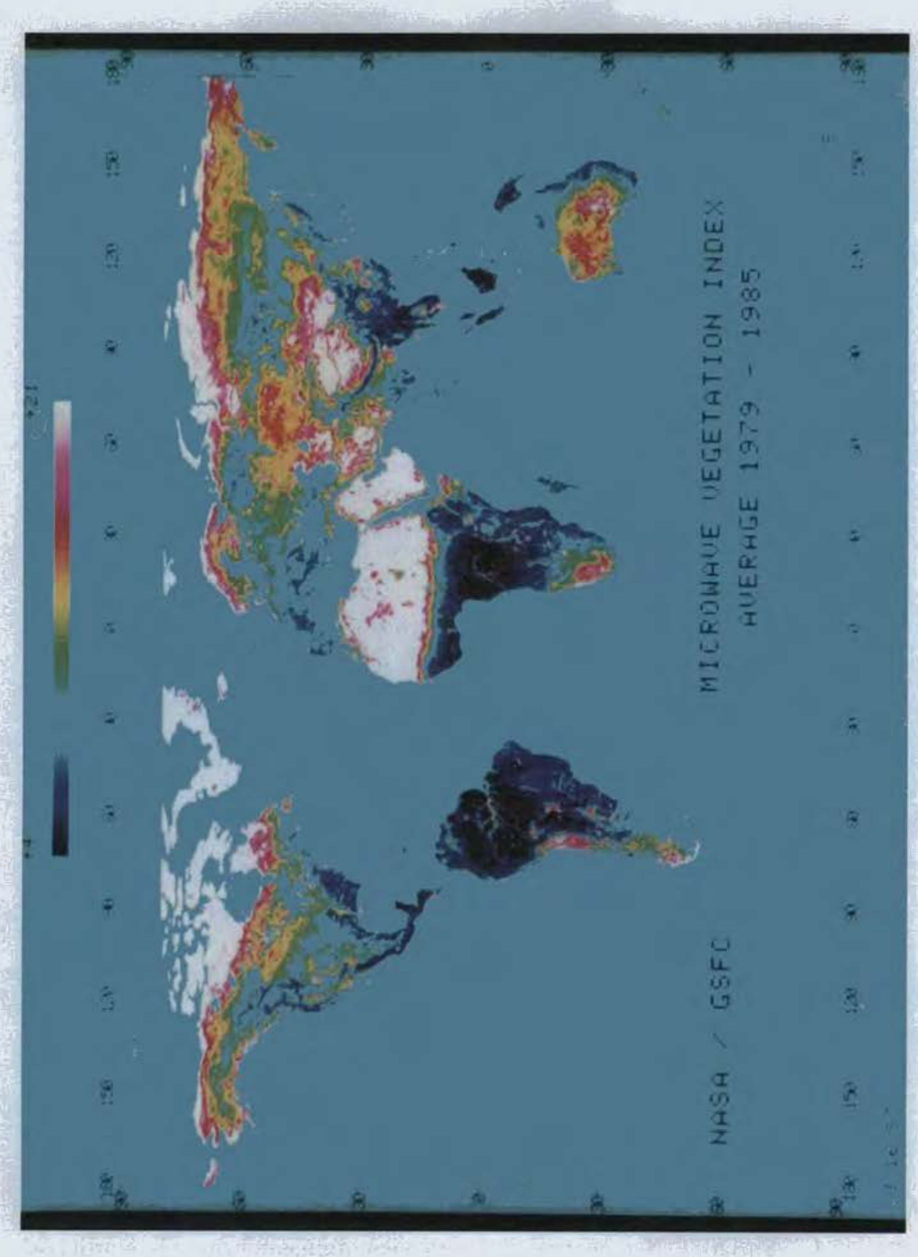

Fig. 2.24 Microwave vegetation index, average 1979—1985 (from B. J. Choudhury and C. J. Tucker, 1987).

2.9. Do observable changes in surface characteristics reflect climate trends?

To approach this difficult question we have first to define accurately what is meant by climate trend and what kind of changes we expect to see. A climate trend is a persistent change of one or more climate variables such as temperature, distribution pattern and/or amount of precipitation (Figure 2.25), cloudiness etc. How long the change has to last to be called a trend depends on the time scale of a specific investigation; but if it is less than a decade, it would be referred to as variability. Changes that we can identify at the surface include those of albedo, vegetation density, length of vegetation period, snow cover, surface temperature, and soil moisture in the uppermost layer. Vegetation changes clearly reflect the availability of water and therefore seem to be good indicators of some hydrological processes. Indeed, large variations in vegetation density have been detected from one year to another. However, they have to be interpreted carefully. In 1985, for example, there were high levels of vegetation in parts of the Sahel though it was not exceptionally wet. The reason was that most of the animals that normally ate the grass died during the preceding drought. The grass even continued to remain in place as dried hay, modifying the albedo of the region. Such effects have to be

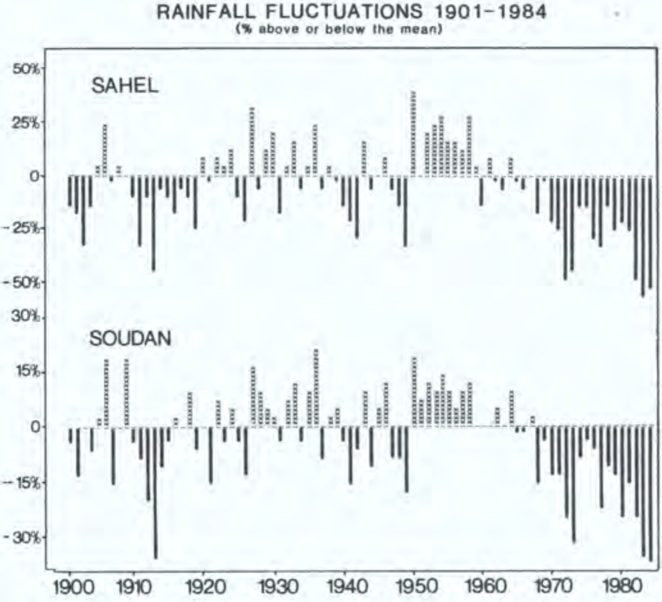

Fig. 2.25 Variation of annual rainfall in two environmental zones in North and West Africa. Scales: per cent deviation from normal (from S. E. Nicholson and D. Entekhabi, 1986).

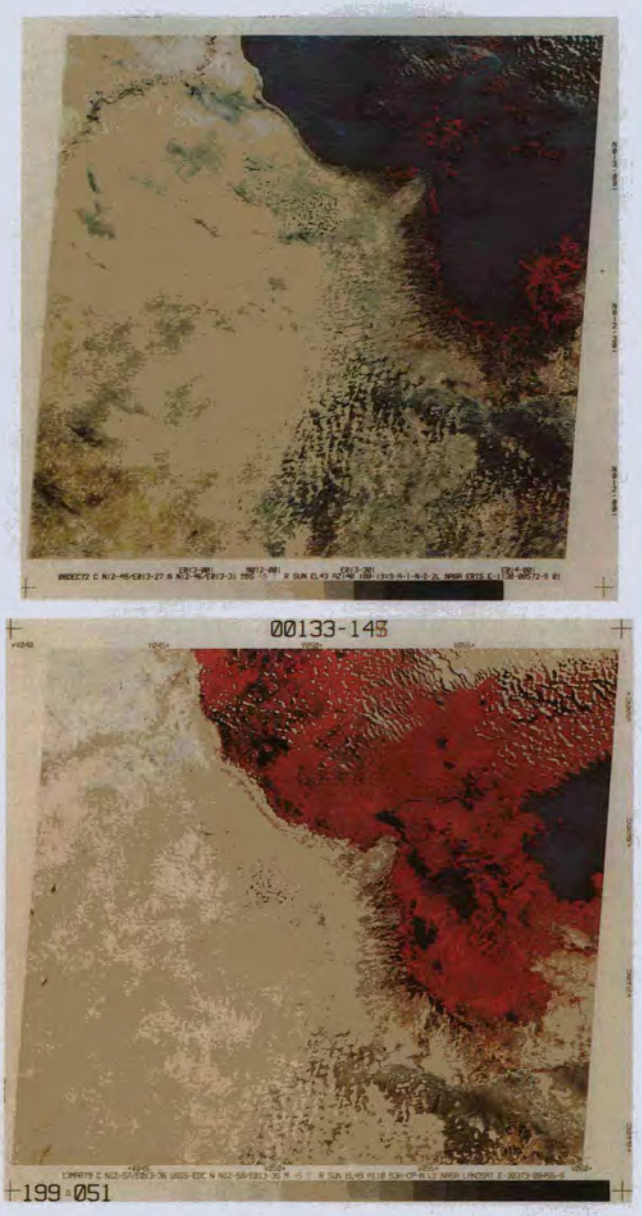

Fig. 2.26 Change of coastline of Lake Chad and change of vegetation cover in this area. LANDSAT MSS band 7, 8 December 1972 (top) and 13 March 1979 (bottom) (by courtesy of NASA).

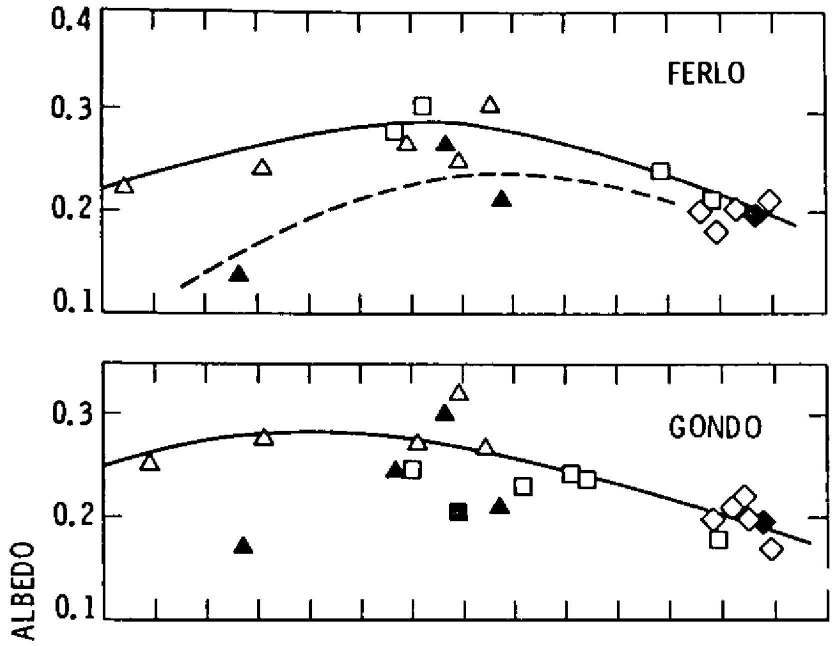

Fig. 2.27 Albedo history of the western Sahara and Sahel between 1967 and 1979 from different data sources. Filled symbols correspond to observations in the rainy season (from M. F. Courel, 1985).

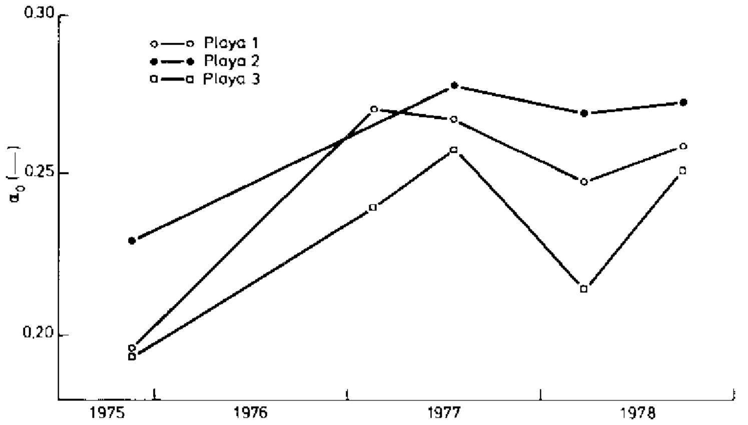

Fig. 2.28 Variation of average reflectance of three playa lakes in West Libya (from H. Kuipers and M. Menenti, 1986).

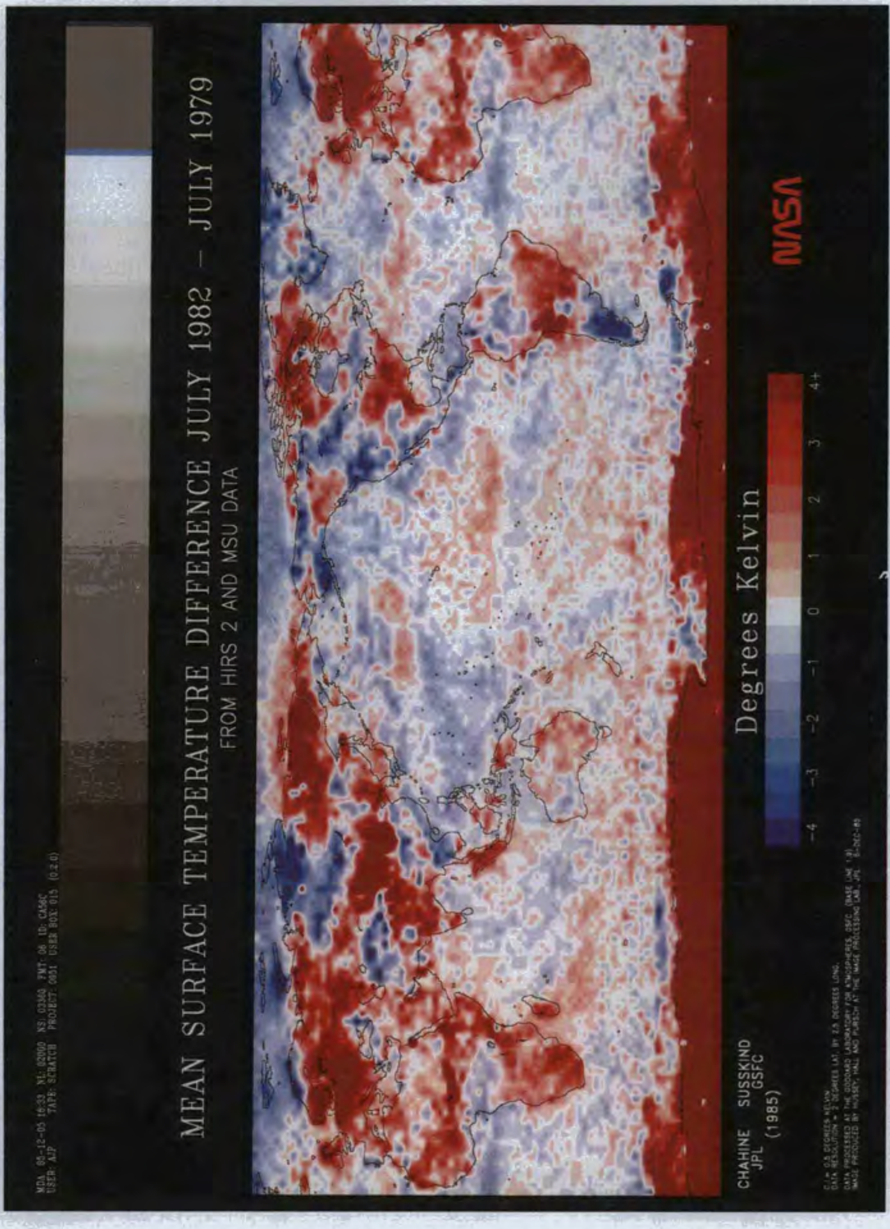

Fig. 2.29 Mean Earth surface ("skin") temperature difference July 1982—July 1979 (from M.T. Chahine et al., 1986).

accounted for in time series of satellite observations, to discriminate climate trends from superimposed effects. This emphasizes the necessity of anchor stations (see Chapter 4.6.) in critical regions. So far there have been few attempts to evaluate time series of satellite data in order to assess changes which cannot be attributed to the action of man.

One example is the change of the coastline of Lake Chad which is certainly an indicator of the hydrology in the Sahel (Figure 2.26). The evaluation of data from different satellites to determine albedo changes in the Sahel is also well-known. These data suggest an albedo peak around 1973 and a decrease since then (Figure 2.27). Yet another example was reported for playas in West Libya (Figure 2.28). Here an albedo increase was detected after 1975, suggesting increasing dryness.

Surface temperature changes (Figure 2.29) are also very interesting. While the direct influence of the clouds on the emission temperature seems to be fairly well removed (there are no abrupt changes over the oceans), it is not so clear whether the differences over the continents might not be the indirect result of persistent cloudiness which may greatly reduce the surface temperature. A long time series is needed in order to confirm any real trend.

With increasing accuracy of satellite measurements and sophistication of evaluation methods it will become feasible to prepare large uniform sets of data. If such data evaluation projects can be continued for about ten years there is a real chance to quantify the changes in land-surface characteristics and a careful interpretation could also remove man-induced or other interfering effects.

3. HOW THE LAND-SURFACE CHARACTERISTICS ARE DERIVED FROM SATELLITE MEASUREMENTS AND HOW THESE METHODS HAVE TO BE IMPROVED

3.1. What primarily is measured and what information finally is needed: The role of models

Satellite sensors measure directly the electromagnetic energy impinging upon their detectors. Each of these detectors transforms this energy into an electric signal which is amplified, digitized, transmitted to various ground stations, archived and recorded on magnetic tape. The recorded numbers are directly related to the radiances at the top of the atmosphere at a particular time of observation, spatially integrated within the instantaneous field of view (IFOV) of the radiometer and spectrally integrated over the band passes of the instrument.

In order to interprete satellite data quantitatively, it is necessary to know the relation between these data and the quantities required for different applications. It is the role of evaluation models to establish these relationships.

The conversion of the satellite data into the desired information requires in fact the application of two classes of models:

- geometrical models that relate the position of a pixel in the recorded image to the correct position at the Earth's surface.
- the energetic and radiometric models that relate the signal observed at the top of the atmosphere to the relevant quantity in the corresponding area of the Earth's surface.

To infer the properties of the land-surface from the received signals, in general the following steps are necessary:

- The signals have to be converted to an absolute scale in radiances. This requires an adequate calibration of the instruments, which is not always provided.
- The spectrally selective measurements have to be correlated with the required spectral information. This involves intercalibrations between different satellite systems.
- To remove the interfering effects of the atmosphere such as atmospheric scattering, absorption and emission corrections have to be applied. The pixels filled with clouds have to be removed or the equivalent cloud free signals be restored.
- The pixels have to be located geographically.
- Models have to be applied to relate the measured and corrected radiances to the appropriate surface.

3.2. Why satellite instruments have to be calibrated

In order to derive quantitative information on the parameters of interest, it is necessary to know the absolute values of the radiances recorded. This requires a quantitative relationship between these radiances and the numbers recorded at the output of the satellite radiometers.

For most instruments the relationship between radiances (L) and recorded numbers (N) is close to linear. An example is shown in Figure 3.1 which presents this relationship for NOAA 9 AVHRR channel 2.

This relation is written

$$N = G \cdot L + B$$

The coefficients G (gain) and B (offset) are determined by the calibration, which can be a lengthy and delicate process as the coefficients G and B are specific to each detector and may vary with time. In the absence of internal calibration this implies very good and repetitive measurements of the radiances of adequate targets at the Earth's surface.

Figure 3.2 shows the evolution of the parameters G and B with time for channel 2 of AVHRR. Similarly, ESA periodically publishes revised calibration coefficients of METEOSAT.

In many applications, such as time series over decades, the combination of several scales, the combination of various wavelengths etc., it may be necessary to use data from several satellites simultaneously or sequentially. This implies that an interca-

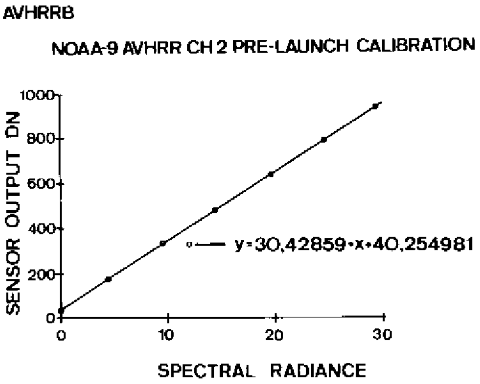

Fig. 3.1 Relationship between spectral radiance and sensor output for NOAA 9 AVHRR Channel 2 (by courtesy of NOAA).

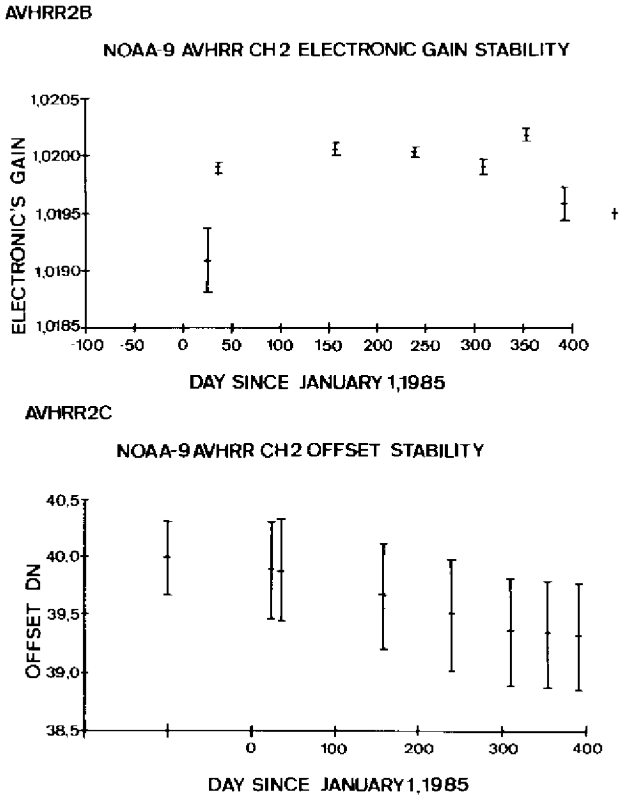

Fig. 3.2 Evolution of the calibration coefficients with time for NOAA 9 AVHRR Channel 2 (see Figure 3.1) (by courtesy of NOAA).

libration between the different satellite radiometers has been established. This task includes a careful analysis of the different spectral responses of the various radiometers involved, of the different calibration methods used, and of the effects of the different pixel sizes. For instance, Figure 3.3 shows the time variation of the reflectance at the top of the atmosphere measured with MSS channel 1 for LANDSAT 1, 2 and 3.

These problems and the results of calibration of various satellites have recently been reviewed in a report on “Satellite Data Availability and Calibration Documentation for Land-Surface Climatology Studies“ prepared in April 1986 by W.A. Malila and D.M. Anderson (ISLSCP Report No. 5). Furthermore a workshop was held at Phoenix in March 1986 to discuss the state of the art on calibration and the problems which have to be solved (ISLSCP Report No. 6).

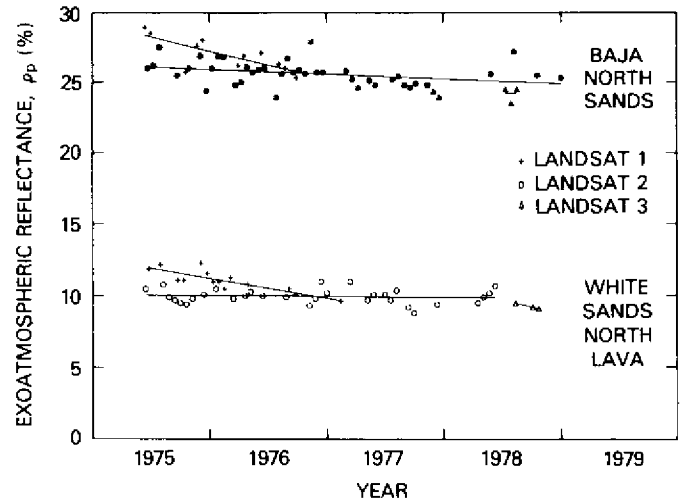

Fig. 3.3 Variation of the planetary reflectance at the top of the atmosphere measured with MSS Channel 1 of LANDSAT 1/2/3 (from R. F. Nelson,1985).

3.3. How to convert satellite data into the desired information

3.3.1. General

Different degrees of complexity are involved in the conversion of signals measured by satellite instruments to useful information, depending on the quantity that is to be determined. It is useful to discriminate between three classes of quantities, primary, secondary and tertiary. This classification implies that primary quantities are needed to obtain the secondary ones and so on.

Primary quantities are directly related to the measured radiance such as reflectance and effective surface temperature. Also indices such as the vegetation index or microwave polarization belong to this category.

Secondary quantities are related to physical processes that occur at the surface such as soil moisture, thermal inertia, heat and moisture fluxes. To determine these quantities the net radiation flux at the surface is necessary that depends on a number of primary quantities like cloudiness, reflectance, as well as temperature and water vapor structure of the atmosphere.

Tertiary quantities are indirectly assessed quantities like the water budget of an area, biomass production, and area averaged evapotranspiration.

Table 3.1. Typical scales for data acquisition devices, models and homogeneous characteristics of surfaces.

Scale m^2	Data acquisition	Models	Homogeneous Characteristics
10^{-2}	In situ	Local models	Soils
10	In situ	Boundary layer	Plant
10^2	SPOT, RBV		Buildings, Streets
10^3	Landsat TM		Cultivated fields
10^4	Landsat MSS		Forests
10^6	Tiros AVHRR		Lake/Ocean/Ices
10^7	Meteosat, Goes		
10^9	Nimbus — SMMR	Meso-scale	
10^{11}		GCM	

The different evaluation steps require evaluation models or algorithms of varying complexity. In some cases these models have a similar structure as those used to compute fluxes of different kinds in atmospheric circulation or boundary layer models. In the latter case fluxes are computed from a set of parameters which are either predetermined as boundary condition or adjust themselves interactively in the model. For the evaluation of satellite data the models are sometimes used in an “inverted“ way. From observable quantities simulated by the model those parameters are inferred that are desired as basic information. Because these models are used in their evaluation mode in the opposite way to that of climate or general circulation studies, they are sometimes called “inverted models“.

The general and simple definitions of land-surface parameters in models do not generally account for the complicated reality of scale-mixing imposed by the very different satellite-pixel sizes, the typical size of homogeneous areas and the scale of the grids of the models using these parameters. Typical scales are listed in Table 3.1.

3.3.2. Inference of primary quantities

The general scheme of inference of primary quantities is about the same for all of them. It is briefly summarized in Table 3.2. which indicates the main problems occurring at each step of the process.

A typical example of geometric corrections is given in Figure 3.4 which shows the reconstruction of a METEOSAT image of Tunisia over a geographically located

Table 3.2. General scheme of the derivation of primary surface quantities

OPERATION AND APPLIED METHOD	PROBLEMS
Localisation of a pixel at a geographical grid: navigation, geometrical correction, digital correlation to a reference image or visual correlation	- Knowledge of actual orbital parameters and of the attitude of the satellite - Relief effect - Necessity of a data bank of controlled land marks
Determination of cloud-free pixels: minimum radiance over a week or a month, thermal and visible bidirectional histogram, thresholds, classification	- Cirrus contamination - Dust clouds - Variation of bidirectional reflectance and albedo with angle of observation moisture
Corrections for atmospheric effects and intercalibration (using either HIRS 2 and MSU on board of NOAA satellites or images such as NOAA/AVHRR; possible use of GOES-VAS): angular analysis using radiative transfer models, split window technique	- Reference sources on board - Intercalibration with other radiometers - Well-known reference test-sites - Application of inversion technique to infer air temperature and humidity profiles, large data bank to achieve quick convergence of the algorithm - Aerosol distribution and aerosol optical properties - Spectral variability of Earth's surface emissivity
Cloud discrimination:	- Angular variability of the cloud bidirectional reflectance - Brightness/absorption relationship - Cloud type
RESULT: Radiances at the Earth's surface	- in a given spectral band - for a given angle of observation - for a given solar aspect angle
Angular and spectral integration respectively extrapolation **Application of an evaluation model** ("inverse model") **Calibration against other observations, application of an empirical relationship**	- Necessity of models of the bidirectional reflectance and of variability of various types of surfaces - Digital terrain models - Narrow-to-broad-band conversion - Application of inversion techniques, stability of algorithms, a priori data banks
RESULT: Bulk surface parameters at satellite pixel size such as albedo, "skin" temperature, net radiation fluxes, heat and moisture fluxes	
Validation of the results by comparison with field measurements	Methods to obtain reliable data of quantities that are representative for an image pixel as a whole

Fig. 3.4 Restitution of a METEOSAT image of Tunesia over a geographically located grid (by courtesy of D. Ho/IBM Science Center).

grid. Such relocation allows an intercomparison on a pixel by pixel basis of different kinds of satellite data. For instance, Figure 3.5 shows two images of La Crau (SE of France) at the same scale from TM MSS 6 (top) and AVHRR 5 (bottom).

The input to the atmosphere-surface system is the extraterrestrial irradiance. By a satellite radiometer the radiance is measured in a direction determined by its instantaneous field of view. The directional reflectance of the surface must be inferred under the existing illumination conditions. This illumination results from direct solar radiation and scattered sunlight. A radiative transfer model has to be applied to determine the irradiance at the bottom of the atmosphere and the modification of the reflected radiance by the atmosphere on its way back to the satellite. These radiative transfer models can often only be operated with climatological information about atmospheric turbidity and aerosol optical properties.

Atmospheric corrections are also essential in the thermal infrared bands. The atmosphere can induce errors larger than 5 Kelvin. In the visible and near infrared the observed radiances are furthermore spectrally distorted by varying path lengths. The distortion depends on the angle of observation. As an example, the

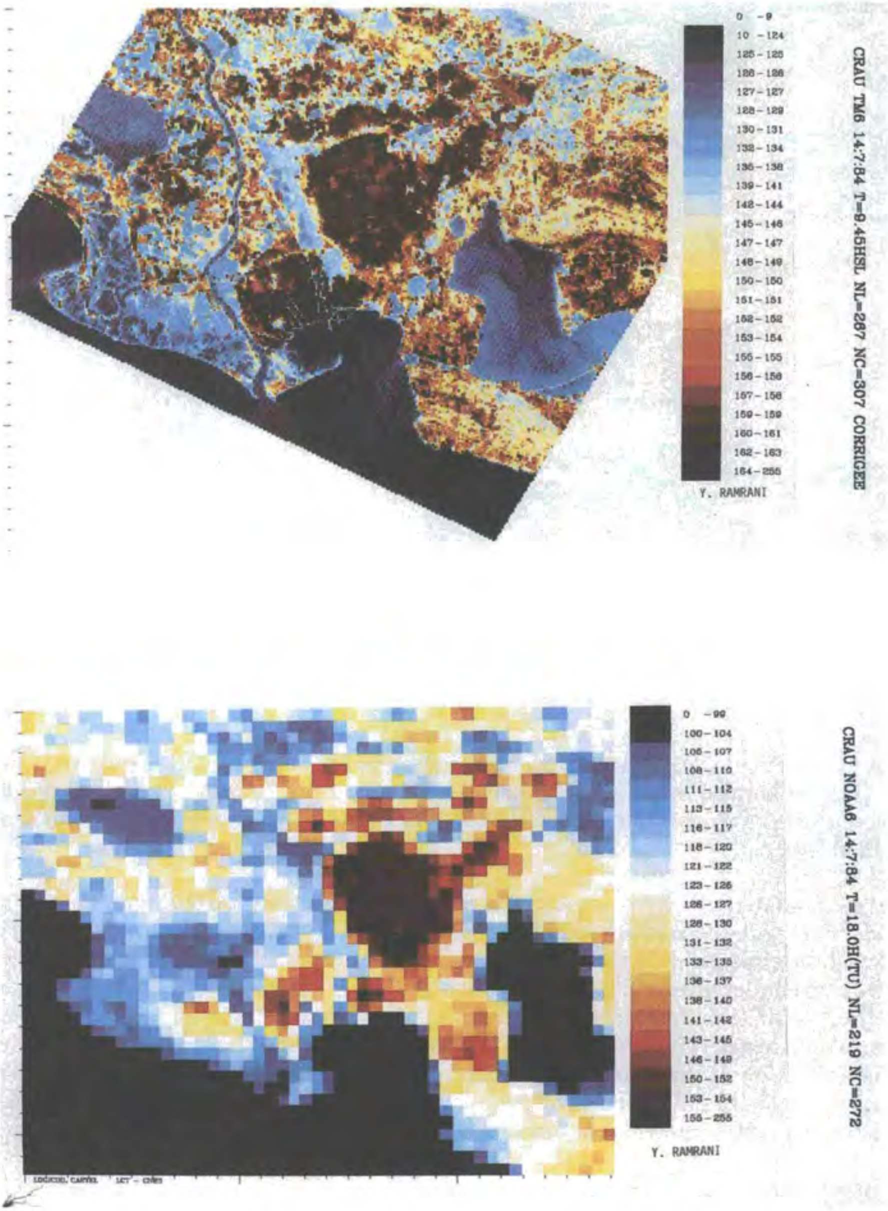

Fig. 3.5 Images of La Crau at the same scale from TM MSS 6 (top) and AVHRR Channel 5 (bottom), 14 July 1984 (from Y. Ramrani, 1986).

influence of atmospheric effects on the normalized difference vegetation index (NDVI) is shown in Figure 3.6.

Time series of land-surface property data require a well-defined sampling rational. The major handicap for a strict application of such a rationale is the cloudiness, which can make it impossible to acquire data during a specified time. The "declouding" of the data is therefore a major task. The NDVI maps of Europe, as shown in Figure 2.11, as an example, are produced from maximum values of each pixel during a 7—10 days period at the end of each month. Consequently they represent a more or less randomly selected vegetation index of a period of about one week. For some months, however, there were not enough cloud-free pixels within such a period, which had therefore to be extended towards the beginning of the month. In a few cases cloud-free pixels could not be found for every location in Europe, so that residual white spots remained in the map. The data represent therefore sampling periods of varying lengths. If the requirement were to sample within a fixed short time interval, larger geographical gaps would have to be taken into account and vice-versa. The sampling strategy is therefore essential for the specification of the future data sets.

Among the problems to be solved, for improving the accuracy of derived surface albedo, is the determination of the spectral and angular variations of the reflection

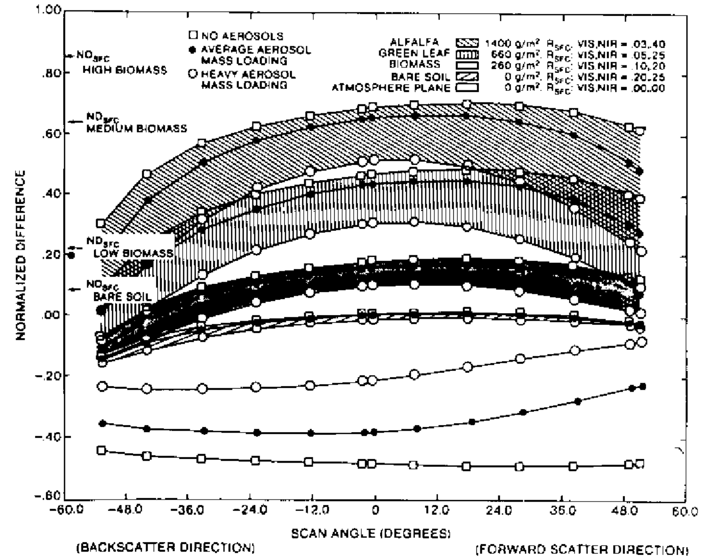

Fig. 3.6 Atmospheric effects on the NDVI simulated for AVHRR viewing and illumination conditions of NOAA 7, winter solstice for different cover types (from B. N. Holben et al., 1986).

by natural surfaces at large scale. The anisotropy of the reflection may induce large errors, as can be seen in Figure 3.7. The anisotropy factor for land (F) enters the formula determining the albedo from the radiances. This angular correction may be as large as 2. These factors have been calculated over various types of land-surfaces and various sun zenith angles and correspond to statistical averages, but for a given pixel they may be quite different from this average. Angular analysis of BDR is therefore of great interest and measurements have already been undertaken over various types of land-surfaces (Figure 3.8). Angular dependence also exists in the thermal infrared bands. Another important problem which has not yet been solved is the determination of the emissivity in the thermal infrared bands as already discussed in Chapter 2.3.

Examples of the determination of primary parameters are presented in Figures 1.1, 2.1, 2.6, 2.7, 2.8, 2.29.

3.3.3. Determination of secondary quantities

The inference of complex quantities like evapotranspiration with the help of satellite data requires already complicated evaluation models that are able to simulate the soil-vegetation-atmosphere system with only a few input parameters. Such models are numerous and cannot be described in any detail within the scope of this brochure. All of them attempt to solve the equation of the mean energy balance and of the water balance. In these equations parameterizations are used of the evaporation from soil and transpiration from plants as well as the transfer of heat and momentum from these surfaces. Advanced models include the soil moisture content in at least two layers, vegetation type expressed by an effective

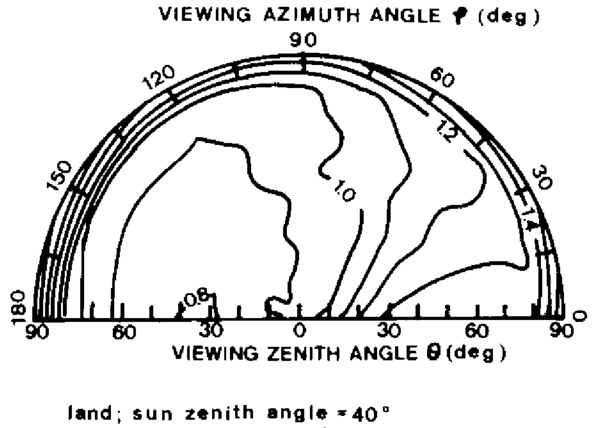

Fig. 3.7 Anisotropic correction factor for land-surfaces (after P. Minnis and E. F. Harrison, 1984).

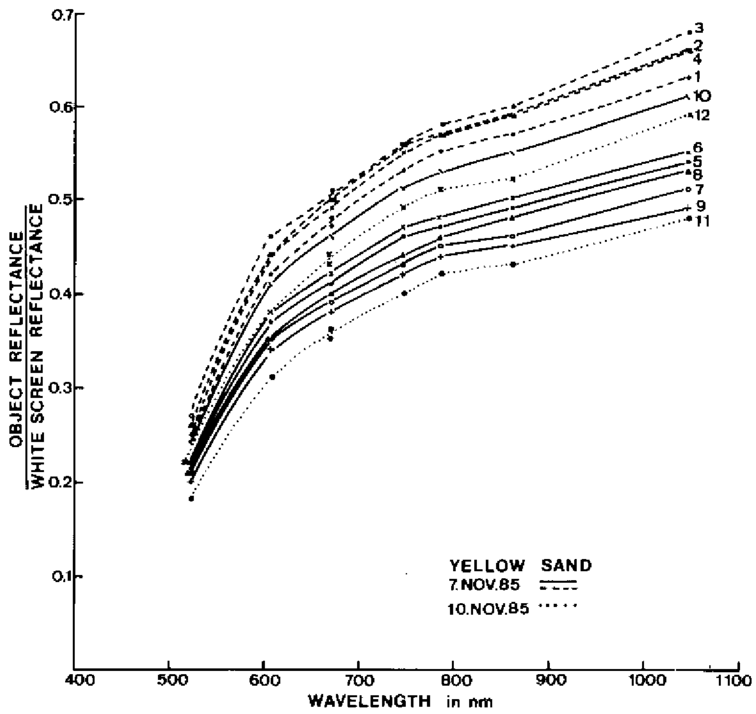

Fig. 3.8 Reflectance measurements over yellow sand in Niger for different illumination conditions. Solar zenith angle ranging from 33° (curve 8) to 62° (curve 4), solar azimuth angle varies from 238° (curve 3) to 122° (curves 5 and 12) and is 162° for curve 11. Azimuth of observation is 175°.

stomatal resistance and the exchange coefficients between both soil and vegetation and the atmosphere also conveniently expressed as resistances (Figure 3.9a).

Once the albedo, the surface temperature and the net radiation flux have been determined from measurements, it is necessary to adjust the internal parameters of the equations for the heat and the mass balances as well as for the transfer of these quantities at the Earth's surface. Instead of solving these equations knowing the land-surface characteristics, like soil moisture, thermal properties and transfer resistance, one is looking for these quantities that yield the measured surface temperature. This is meant by the "inverted" use of these models.

Two types of solution are proposed:

- Statistical types, using regression formulae and giving statistically correct solutions (examples in Figures 2.17 to 2.20)

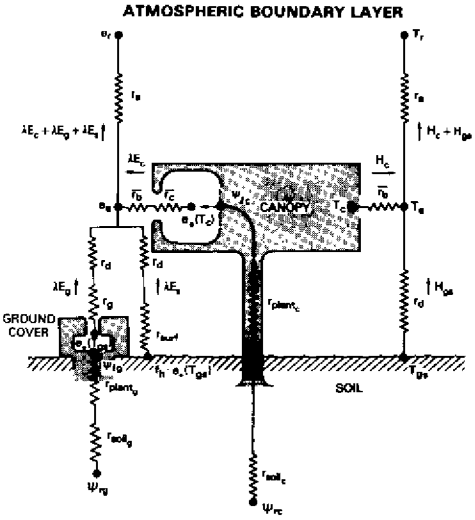

Fig. 3.9 a The transfer pathways for latent heat flux (left-hand side) and sensible heat flux (right-hand side) (from P. J. Sellers et al., 1986).

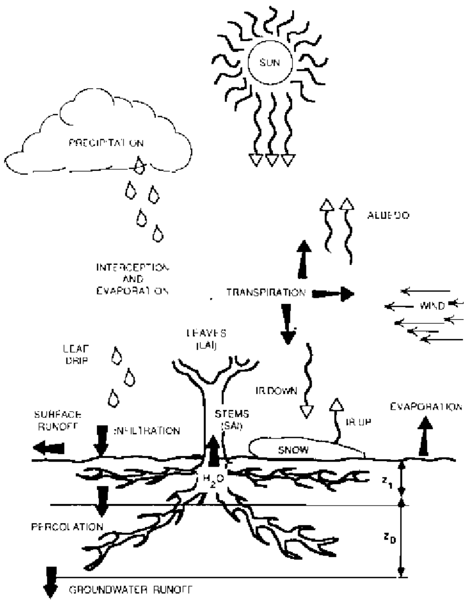

Fig. 3.9 b Schematic of processes involved in surface physics parameterization (from R. E. Dickinson, 1984).

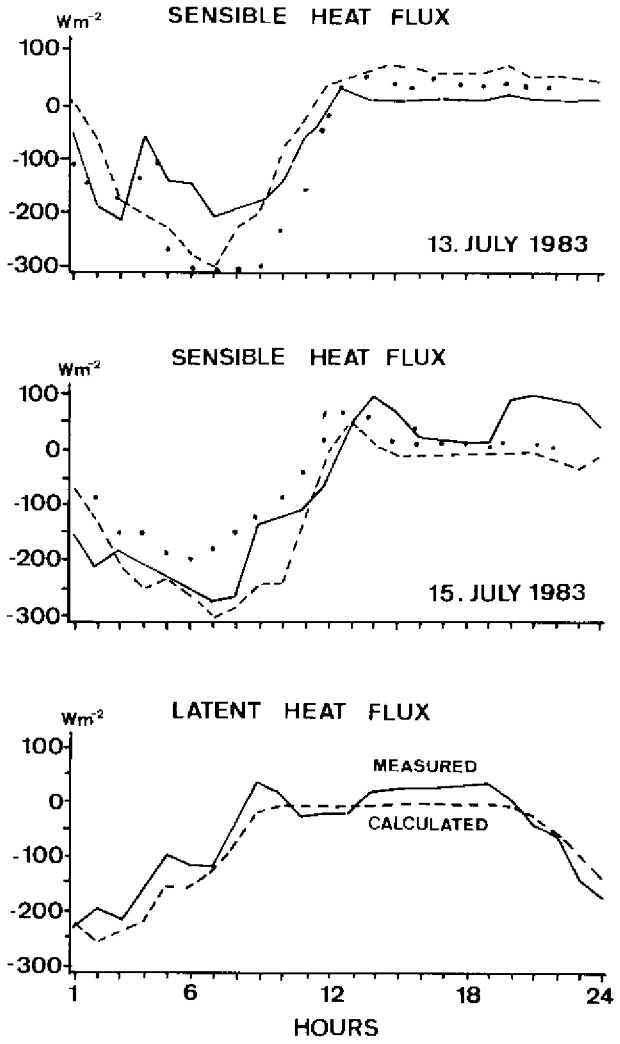

Fig. 3.10 Comparison of model calculations with measured sensible and latent heat fluxes. In the upper two graphs the dashed lines represent the measurements, the dots the model of Taconet (Taconet, Bernard and Vidal-Madjar, 1986) and the full line the Fourier model after Raffy and Bennour (compare Raffy and Becker, 1985). In the lower graph measurements of Lagouarde (1984) are intercompared with the model of Raffy and Bennour. The scale of these models and measurements is still local but applicable also for medium sized homogeneous areas.

- Deterministic types, solving the equation using either Fourier or digitized schemes and inverting them either analytically or using look-up table schemes (example in Figure 3.10).

Comparing the few data obtained from satellites with the numerous parameters entering the equations to be inverted suggests that this process has no unique solution. In order to overcome this problem, either supplementary information has to be given or the models have to be simplified in order to reduce the number of unknowns. Both ways are currently used, although the second one is more appealing, first because experiments and theory have shown that many processes occurring at small scale are smoothed out at large scale, leading to simpler equations as used in GCMs, and second because this will reduce the number of necessary parameters. This simplification should, however, still allow for the most dominant mechanisms as shown in Figure 3.9b.

Instead of being solved these previous equations can be used alternatively to interpolate the quantities of interest between well-equipped ground stations where all these parameters are measured. In that case, only differences have to be evaluated.

The major drawback of all these methods is again the necessity of introducing supplementary parameters not measurable from space, which make them difficult to use over areas where very few ground base data are available. Furthermore many of these models are very sensitive to the accuracy of the determination of the primary parameters which they use as input, leading to large errors in the outputs. For instance, solving the heat transfer equation for LE and considering the daily evapotranspiration $\overline{LE}$ for which the heat flux into the ground is very close to zero, assuming for the aerodynamic resistance a representative value of 30 sm^{-1}, the error in $\overline{LE}$ is approximately given by

$$\Delta\overline{LE} = \Delta R_N + 40\,\Delta(T_s - T_a)$$

where ΔR_N is the error in the net radiation flux and $\Delta (T_s - T_a)$ is the error in the difference between the surface temperature and the air temperature. This relation shows that it requires special efforts to determine $\overline{LE}$ with the accuracies specified for climate studies.

There is not yet a standard method for the determination of secondary quantities from satellite data and experiments have to be conducted to validate existing methods.

3.3.4. Assessment of tertiary quantities

Area averaged budgets of energy and mass fluxes need an approach which includes all four elements: models, ground based measurements, a priori information about soil and vegetation and satellite observations.The HAPEX (see Chapter 4.5) show the way how, as an example, the water budget can be determined with large experimental efforts. The precipitation and evapotranspiration have to be measured in a relatively dense network and the system has to be closed by a control of the run-off from the experimental area. For global overviews there is no way to implement such an observational network. They have to rely much more on satellite observations.

Run-off measurements are possible at major streams. The transmission via satellite of measurements made by automatic stations helps very much to improve the network in certain areas. How the contribution of major source areas for the river run-off vary in time may be inferred from time sequences of satellite observations as discussed in Section 2.6. Hydrological models will be helpful, that allow to determine the retardation of the water flow due to soil and river "resistances". Much experimental experience will be needed to develop schemes for such models in the different parts of the world. Presently we are only at the beginning of such an integrative approach that will have to be developed further within the IGBP and GEWEX.

3.4. What has to be done to present and store the data in an easily accessible way?

It is generally a long and laborious way to proceed from recorded satellite data to the required quantities, especially for large areas and long-time series. Not only are numerous previously presented operations needed, but also the acquisition of the necessary data poses a problem. A consequence of these difficulties is that only a very small percentage of the actually recorded satellite data is effectively used. In order to improve this situation, it is necessary to prepare, store and present the data in a much faster and more easily accessible way than it is done at present. It is needed to develop a data base which should evolve towards an intelligent expert system. This should perform automatically the operations described in Table 3.2. and prepare the necessary input data of the models yielding primary, secondary and tertiary quantities. Such a system can be developed in the following steps:

- Development of a design concept.
- Operation of pilot systems to examine their appropriateness. Such systems have already been developed for ISLSCP in U.S.A. and in Europe. As an example, Figure 3.11 shows a daily cycle of temperature obtained with such a system from METEOSAT and AVHRR data over La Crau (SE of France). This implies the solution of all the problems stated in Table 3.2. including a co-registration and intercalibration of METEOSAT and AVHRR.
- Establishment of a close co-operation between users and data producers in order to prepare a data bank which will inform the user
  - whether a required data set already exists,

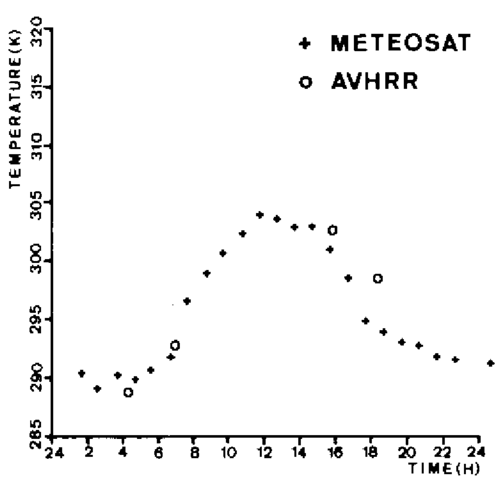

Fig. 3.11 Daily cycle of temperature from METEOSAT and AVHRR over La Crau, 14 July 1984 (after Y. Ramrani, 1986).

- — where it can be found,
- — when it was acquired,
- — how it can be obtained and
- — which operations have already been done on or with the queried data.

- Simplification for users of the access by fast networks to the locations where the various available data are stored and to the locations of expert systems that are capable of pre-processing and preparing the data if necessary.

- Implementation of the procedures to up-date the data base systems with reliable data coming from space and ground based observation systems.

3.5. How can we improve our observational system in the future?

There are three main areas in which our observational system must be improved in the future to become more efficient:

- Accessibility to and reliability of the data
- Optimalization of the observation system
- Improvement of accuracy, stability and reliability of the models and methods used to infer required quantities.

As far as the first point is concerned, large improvements may be expected in the near future when the systems discussed in Section 3.4 are operational. In order to improve the accuracy of acquired data either *in-situ* or from satellite, two aspects need urgent attention:

- calibration of satellite radiometers according to the recommendations by the "ISLSCP workshop on calibration" in March 1986 and
- development of standard methods to measure in-situ parameters representative of large areas.

The second point addresses the status of our observation system. Though it is not in general desirable to increase the amount of observations there are four issues that need to be considered:

- optimalization and unification of spectral bands,
- optimalization of coverage in space and time,
- parallel observations from the same spacecraft in all relevant spectral bands of concern including microwaves and
- pre-processing and selection of data at a very early level, e.g. in the spacecraft itself.

On the one hand it is desirable to combine as much information as possible and to increase therefore the number of parameters measurable from space. Examples of supplementary measurements are directional reflectance, surface roughness, reflectance in the thermal infrared (e.g. by LIDAR), soil moisture in different layers near the surface (multi-frequency microwaves), atmospheric structure and meteorological conditions (e.g. winds) near the surface. Progress in the space systems and in the accessibility to the data would simplify the simultaneous use of data from several radiometers. This would allow

- intercomparisons of large and small scales leading to the analysis of spatial variability, roughness and heterogeneity of large pixels
- complementary use of visible, NIR, thermal IR and microwave bands, allowing a simultaneous measurement of surface moisture and temperature, better atmospheric corrections and a possible determination from space of the necessary meteorological parameters. All these measurements would lead to more accuracy and more stable algorithms.

In order to limit on the other hand the amount of data that has to be processed, useful information has to be separated from useless information (such as visible and infrared observations of the surface in the presence of clouds) at an early stage.

The improvement of models has to proceed in two directions: reduction of the number of necessary supplementary input data (mainly the atmospheric parameters) and improved parameterizations of the fluxes at large scales compatible with GCM grids and satellite pixels. Such parameterizations should use quantities that can be measured directly from satellites. For instance, recent theoretical and experimental work has shown that a near-linear relationship exists between the

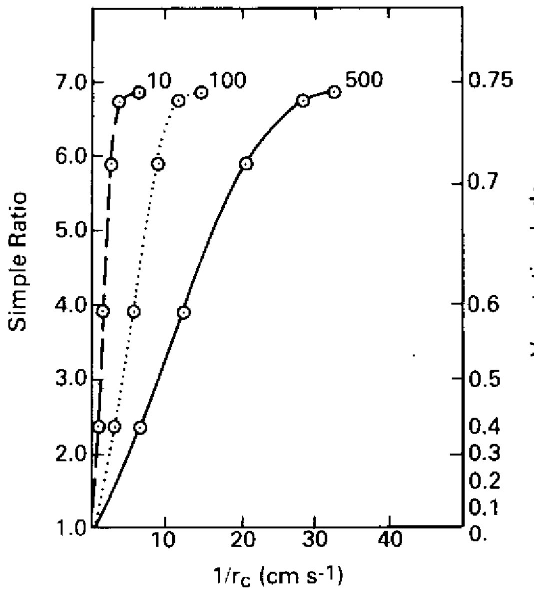

Fig. 3.12 Calculated relation between the simple ratio/vegetation index, inverse conopy resistance $1/r_c$ and incident PAR in Wm^{-2}. Circles refer to LAI of 0.0, 0.5, 1.0, 2.0, 4.0, 8.0 (from P. J. Sellers, 1985).

simple ratio vegetation index and the crop resistance as shown in Figure 3.12. Other parameters of this type have also recently been introduced, such as the normalized microwave index, the scale length and the angular indices. Their relationships with evapotranspiration at large scale have to be examined.

4. WHY GROUND MEASUREMENTS ARE NEEDED TO ENSURE THE QUALITY OF THE DERIVED INFORMATION

4.1. The variability of land-surface characteristics in space and time

The quantities that describe land-surface properties like albedo, emissivity, radiative temperature, and vegetation are highly variable both in space and in time. For global studies only the mesoscale features can be evaluated with respect to their variability. But what does a value averaged over one or many pixels really mean? There is, as an example, the surface or "skin" temperature as measured radiatively from space. The radiance emitted from a surface depends on its emissivity, which can be much less than one for bare soil, and is not a strictly linear function of the thermodynamic temperature of the emitting surface. Between adjacent vegetated surfaces and bare soils the temperature differences can be more than ten degrees. If we cross valleys and mountains, what does an average value tell us? The same is true for the albedo, the quantity that defines the reflected solar flux. From location to location - that can be within meters - not only the average value of the albedo might change but also the spectral characteristic of the albedo. Since also the solar flux exhibits a specific spectral distribution (that is even modified by the amount of atmospheric water vapor) its product with the spectral albedo and a successive integration over the spectrum may even locally yield quite different results in comparison with the multiplication of the total albedo times the total incoming solar flux.

The products derived from satellite measurements can only be validated for small areas where direct measurements are available. The smallest unit for such validation is the size of a pixel that can be from 400 m^2 (SPOT) to 2500 km^2 (microwave radiometers). Also at the size of an AVHRR pixel of 1 km^2 substantial integration is already effective. It is therefore of utmost importance that the satellite data are used in a correct way, taking into account how they are generated, what the real meaning of an average value is, and how they can be used in models.

4.2. The ISLSCP validation strategy

In view of the difficulties arising from the natural variability, a validation strategy was developed that proceeds stepwise from high resolution data to larger pixel sizes and from quantities that can be derived relatively straightforward to more complex information.

The simplest way to validate a simple quantity such as temperature or a reflectance value for a sensor with high spectral resolution as obtained by SPOT, LANDSAT or MOS-1 is to select an area with homogeneous elements of at least 3 × 3 pixels. The quantity in question, temperature or directional reflectance, is evaluated at the

Table 4.1. Nomenclature of ISLSCP experiments

Scale	Area	Level	Effort
α	1 — 100 m^2	1a	Control of a single quantity or a simple process at very local scale (α) or at a few pixels scale (β) mostly in representative homogeneous terrain.
β	1 — 100 km^2	1b	Validation at a few pixels scale (β) in homogeneous or simply structured terrain of complex parameters or processes.
γ	10^4 — 10^5 km^2	2	Complete control and measurements of heat and mass transfer at scale γ (HAPEX-type experiments). Studies of area averaging techniques. Determination of quantities at the grid scale of General Circulation Models.

ground for one or a few points in this area to establish a reliable average value. In addition the atmospheric transmittance is measured or determined independently. In the case of temperature, atmospheric transmittances may be derived from radiosonde ascents made in the vicinity. Then the satellite data are processed for atmospheric effects and compared with the value measured in situ. To validate the result for a larger pixel of another instrument it would be necessary to intercompare it over the same area with the "calibrated" measurements of the high resolution sensor. Such experiments can eventually be carried out by a single small group, since only a few parameters have actually to be measured. This kind of intercomparison is called "Level 1a" experiment, and depending on the scale, the letters α for a local 1 — 10 m control experiments or β for a 1 — 10 km experiment are added (Table 4.1).

If we turn to more complex quantities the scale automatically widens to some km, to approximately 10 × 10 km^2, to accomodate at least a small number of AVHRR pixels that provide more frequent data than e.g. LANDSAT. In this case more equipment has to be used at the ground in order to cover the area which should still be very homogeneous. Also, if the validation is for energy fluxes, rather sophisticated instrumentation has to be used, supplemented by measurements from aircraft, which play a major role in the area averaging process. These are "Level 1b" experiments, at the scale β.

To determine these quantities over heterogeneous terrain including the water budget, experiments are needed that cover a whole catchment area of the order of 10^4 to 10^5 km^2. Such experiments are only possible if a basic background network can be maintained over a longer time, say two years, in which intense observing periods are included lasting for a few weeks. In this case aircraft measurements are mandatory as there are no other means of integration over such an area. Here we are arriving at the dimension of a HAPEX (Hydrological Atmosphere Pilot Experiment) defined by the JSC for the study of hydrological budgets and modelling of hydrological processes.

4.3. Verification of single quantities: Level 1a experiments

In order to validate the inference methods described in Chapter 3, the spectral irradiance at the surface, the outgoing radiance in the direction of the satellite and the transmission through the atmosphere in the direction of the satellite have to be determined. To relate this spectral information to quantities needed in models like total albedo and total radiation fluxes these spectrally integrated quantities have also to be measured at the ground.

The spectral transmittance through the atmosphere can be determined by an actinometer equipped with appropriate filters. This instrument measures in the direction of the sun and the transmittance determined in this way has to be adjusted for the satellite aspect angle.

The irradiance at the surface is measured by a calibrated pyranometer with a hemispherical field of view. The radiometer for the radiance measurements generally has a field of view of very few degrees. If it is not possible to mount it at some distance from the surface it will pick up the micro-scale variability of the surface reflectance and has to be moved around.

The measurement of the irradiance and the reflected radiance at the ground is often reduced to two radiance measurements where one is towards a special calibrated isotropic reflecting and horizontally oriented surface (such as MgO powder) and the other towards the object. In other approaches it is not the outgoing radiance that is measured but the surface albedo and a reflection model to relate the albedo to the directional reflectance is required. The albedo and the reflectance characteristics may also depend on the solar zenith angle. Thus the validation has to be done for the different times of satellite overpasses. Similar problems arise for temperature and vegetation index validations.

In the case of the vegetation index it is difficult to calibrate against vegetation properties. This needs long observation times or repetitive measurements in the field and — often destructive — measurements of the vegetation quantities. Very interesting correlations have nevertheless been found between the biomass production and the NDVI, the normalized difference vegetation index, as is illustrated in Figure 2.12.

4.4. Verification of complex quantities at a medium scale: Level 1b experiments

The deduction of secondary quantities requires the application of more sophisticated evaluation models. In order to validate the deduced product it is in most cases not sufficient to concentrate on one of these quantities. It is, in fact, necessary to close the whole system to which this component belongs. In practise this means that the whole energy budget has to be measured at the ground. This includes measurements of the radiation budget, the sensible and latent heat fluxes into the atmosphere and the heat flux into the soil. Different approaches exist for the measurement of the heat fluxes. These can be deduced from profile measurements of wind, temperature and moisture, or eddy correlation techniques can be applied using sonic anemometers and Lyman-alpha hygrometers, or the total heat flux can be determined as the difference between the radiation budget and the heat flux into the ground. In the latter case the components of the total heat flux — sensible and latent heat — can be determined by means of a Bowen-ratio measurement for which essentially the dry and wet temperatures at two levels are necessary.

Different flux measurement systems have been intercompared with each other and with satellite data at a European experiment in La Crau, France, in June 1987. The area covered about 50 km^2 and eight groups with more than ten masts of which two were 25 m high, participated in the experiment (Figure 4.1).

On a larger scale the U.S. FIFE (First ISLSCP Field Experiment) experiment took place at about the same time in the Konza Prairie near Manhattan, Kansas. During this experiment a large number of measuring stations were distributed over an area of about 225 km^2. Experiments over such an area raise the question of the sampling problem. FIFE was therefore designed to attain an experimental methodology for use in designing subsequent experiments. To achieve this objective, efforts were made to acquire data over a range of spatial scales. These data will be used to test various methods of integrating our understanding of small-scale processes (e.g. photosynthesis, transpiration, scattering of light by leaves) up to the scale of satellite pixels of various resolutions. Two issues must be tackled as a direct consequence of this objective. The first is that data must be acquired in order to validate integration procedures, the second is that the effects of coarsening resolution on radiometric data must be studied explicitly. In this sense the focus of FIFE is directly bound to the problem of studying processes and states over a range of scales, from individual plant leaves up to fluxes over the entire site (Figure 4.2). The following data acquisition strategy was applied to achieve this objective.

- Radiometric data: These data were collected at the leaf 10^{-2} m^2, canopy 1 m^2, flux station 10—100 m^2 scales and linear satellite resolutions of 10 m, 30 m, 100 m, 1 km and 8 km scales using a range of ground based, airborne and satellite instruments.

- Flux data: These data were collected at leaf, canopy and flux station scales as defined above and also at scales comparable to the whole site, i.e. 100—200 km^2. Pyranometers, flux meters, Bowen-ratio, surface and airborne eddy correlation and LIDAR equipment were utilized to perform these tasks. Fluxes of heat,

Fig. 4.1 Masts for heat and moisture flux measurements at La Crau.

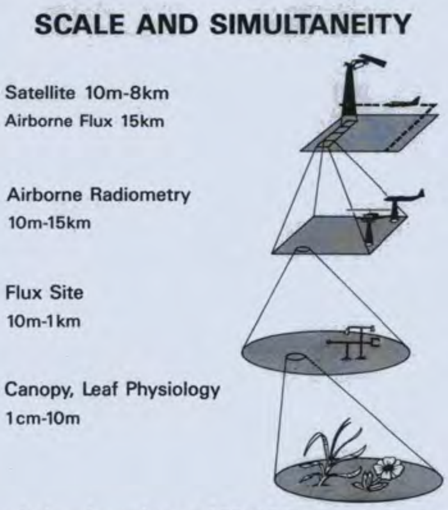

Fig. 4.2 Scales and simultaneity of ISLSCP experiments (by courtesy of P. J. Sellers).

water vapor, and CO_2 are studied at all scales while momentum flux is observed on the flux station and at larger scales.

- Biophysical data: Vegetation physiological data, physical and optical properties, soil physical properties, soil moisture, etc. were acquired. These data will be used to check the prognostic variables in various simulation models of surface processes.

The varying terrain of the FIFE site posed some challenges with regard to location and areal integration of ground measurements. This is especially true for those parameters which will be measured at a limited number of micrometeorological stations. These stations included 16 Automatic Meteorological Stations (including 4 super-AMS stations), 16 Stations for measuring Bowen-ratio and 6 Eddy Correlation Stations.

They have been located on two principles from sampling theory:

(1) For a heterogeneous population, the sampling error of an estimated parameter can be reduced by stratifying the population into more homogeneous sub-populations, and sampling each stratum proportional to its size and relative variability. This presumes some a priori information about the behaviour of the parameter over the region.

(2) For spatially distributed samples, non-periodic random sampling over a region is inefficient because of the poor distribution of resulting information. Particularly for small samples, periodic random spacing of samples provides maximal information for a regional variable.

The FIFE site has been stratified into eight strata, four topographic regimes (plateau, valley bottom, moderate slope [3^0—8^0], steep slope [$>8^0$] and burned or unburned). Digital elevation data were used to estimate the frequency distribution of topographic classes. The proportion of the FIFE site burned in the upcoming season and the variability of surface climate parameters within each of the eight strata were roughly estimated. Note that the preponderance of the area is classified as burned moderate slopes, while the smallest strata are unburned plateaus, valley bottoms and steep slopes.

At this scale it becomes important to involve aircraft for the integration of the data. In FIFE six aircraft participated in data collection. These were the NASA C-130 (see Figure 4.3), the NASA H-1 Helicopter, the NCAR King Air, the Wyoming King Air, and the National Aeronautical Establishment (NAE), Canada, Twin Otter and the NOAA Aerocommander.

The primary objective of the NASA aircraft and the flux aircraft (NCAR, Wyoming, NAE) is to collect near simultaneous measurements of the radiation, heat,

Fig. 4.3 NASA C-130 aircraft equipped with remote sensing instruments during the FIFE experiment.

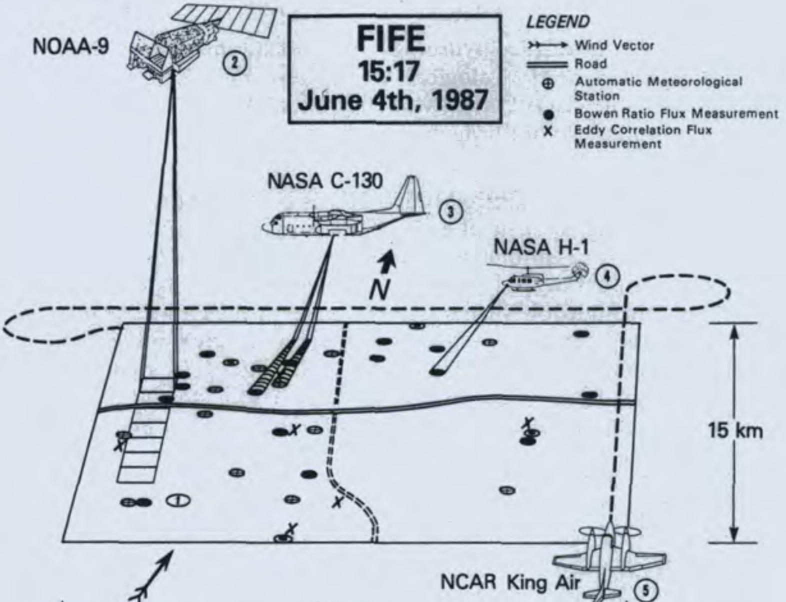

Fig. 4.4 Situation at the FIFE site at 15:17, 4 June 1987 time of NOAA9 overpass (by courtesy of P. J. Sellers).

water vapor, CO_2 and momentum fluxes over the site. In addition, the flux aircraft provides estimates of the turbulent kinetic energy over the site. Figure 4.4 shows how the aircraft are deployed at the time of satellite overpass.

Another concept is the LOngitudinal land-surface TRaverse EXperiment (LOTREX). It consists of a series of experiments at a scale between the La Crau and the FIFE under a variety of climatological conditions. The areas of investigation are selected by means of satellite data (primarily the vegetation index and its variation in time) as well as on the basis of homogeneity over several pixels. Some LOTREX field experiments in the vicinity of 10° East have already been defined. The first experiment of this type will start in May 1988 in the Federal Republic of Germany. It is proposed to extend this traverse from here southward to Africa where a pilot experiment is planned for spring 1988 in Niger. This experimental strategy could probably also be applied in the Americas and Asia to investigate cross sections through the continents especially in areas with strong climate gradients, and to cover more complex terrain.

4.5. Verification for a region of the size of a hydrological basin: Level 2 experiments

For the study of land-surface hydrology and climate interaction the JSC for the WCRP has designed the Hydrological Atmospheric Pilot Experiments (HAPEX) of which the first one, MOBILHY (Modelisation du Bilan Hydrique), was carried out in France, south-east of Bordeaux in 1986.

The principal focus of HAPEX-MOBILHY is on the hydrological budget and evaporation fluxes at the scale of a GCM grid square i.e., of the order of 10^4 km^2. The main purpose is to conduct a monitoring and field program that will provide after one year (or possibly two years) a data base including hydrological, pedological, surface, and atmospheric parameters against which it will be possible to test and develop parameterization schemes of the hydrological budget and evaporation to be implemented in atmospheric GCMs. The data include information about sub-surface and surface hydrology (upper-soil moisture content, water-table height, precipitation and stream runoff), land-surface parameters (vegetation cover, albedo, surface temperature) as well as atmospheric processes, and parameters (turbulent latent and sensible heat fluxes, surface radiative budget, cloud cover, vertical structure), see Figures 4.5 and 4.6.
The observational program began on 1 April 1985 and continued for approximately two years. It included a special observing period (SOP) from 1 May to 15 July 1986, during which additional observational and measuring systems were instrumented, as the NCAR King Air, specially equipped for turbulent-flux measurements, and the NASA C-130 aircraft, specially equipped for remote sensing (Figure 4.3.).

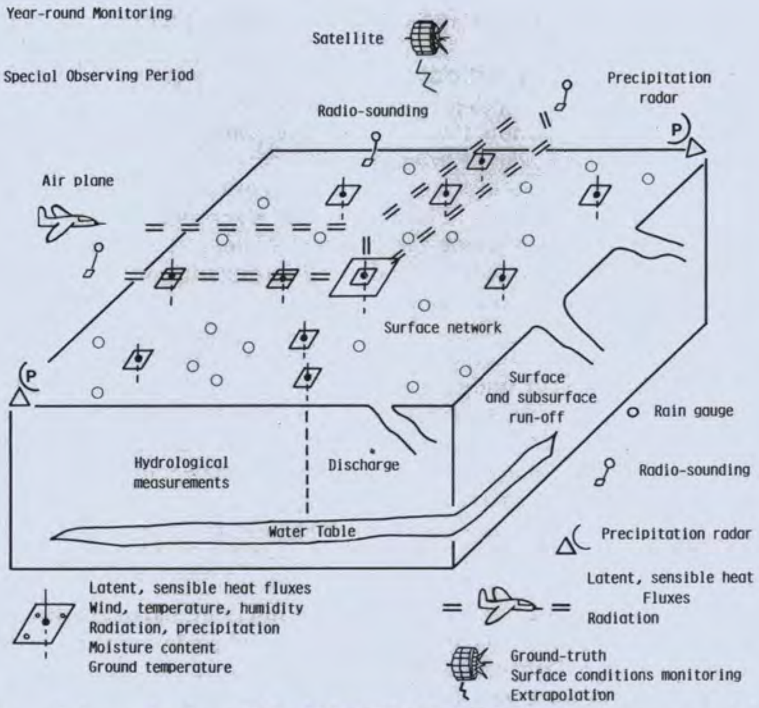

Fig. 4.5 Schematic view of the HAPEX-MOBILHY experiment area (after J. P. Goutorbe, 1986).

Fig. 4.6 Measurement of stem run-off during HAPEX.

4.6. ISLSCP anchor stations and criteria for their selection

4.6.1. Purpose of anchor stations

The ISLSCP Implementation Plan foresees the production of global sets of land-surface data being started around 1990 and becoming fully operational around 1996 with the advent of the new generation of Earth observing platforms. At that time the development will be finalized of algorithms to convert satellite radiances into information about the physical/biological state of the Earth's surface and their ability to deduce the derived information will have been validated by a number of field experiments.

With the operational production of land-surface data the basic algorithm research including the related field studies will probably slowly decline while advanced research with the data sets increases. Such studies, e. g. in context of Global Change research, have to rely on the quality of the information derived from the satellite measurements. Changes in instrumentation and degradation of sensors as well as the development of advanced evaluation techniques will make it highly desirable to check continuously on the performance of the system and the updating of calibration data.

It is suggested that this be done at that time by an international network of ground based observation stations, which are in co-ordinated communication with each other and regularly perform certain measurements that can be used to recalibrate all components of the observing system and to check on the derived quantities.

These stations are called anchor stations.

4.6.2. What has to be measured at anchor stations?

All quantities which are inferred from the satellite measurements and which are needed to interpret the primarily measured radiances have to be monitored. These are

- albedo (spectral and total)
- reflectance in the direction of the space platform
- radiometric surface ("skin") temperature
- emissivity
- temperature profile (-1 to + 20 m, final height depending on roughness)
- components of the radiation budget
- precipitation
- soil moisture down to approximately 2 m
- sensible heat flux
- latent heat flux
- microwave emittance
- precipitation

- vertical temperature and humidity profiles with radiosondes or other advanced vertical sounding equipment
- (spectral) optical depth of the atmosphere
- vertical aerosol distribution (LIDAR), if possible
- aerosol type
- visibility range
- vegetation type
- biomass production
- structural parameters of vegetation, leaf area index
- stomatal resistances.

4.6.3. Where would be the best sites for anchor stations?

Though some basic measurements may be continuously recorded at the stations, it is not yet foreseen that all quantities will be measured at any one time. The stations should be used to provide complete data sets for the main seasons or, if necessary and if so decided by world-wide co-ordination, during special intense observing periods.

The signals received from the surface and the interference with the atmosphere vary very much with climate for which we distinguish eleven major climate classes (after Köppen):

- tropical rain forest
- tropical savanna
- steppe
- desert
- temperate rainy with dry winter
- temparate rainy, moist in all seasons
- temparate rainy with dry summers
- cold snowy forest, moist in all seasons
- cold snowy forest with dry winter
- tundra
- icecaps.

All anchor stations should be representative of an area that covers at least 9 pixels of future meteorological satellite measurements (approx. 10 × 10 km^2). By the totality of all anchor stations the major climate zones as well as the major vegetation types should be represented. Nevertheless it is believed that in total not more than 12 such stations — about two on each continent — are necessary and feasible. The surroundings of the anchor stations should be suitable for larger field experiments that may become desirable in the future.

It would be advantageous if these ISLSCP anchor stations could be combined with other planned land-surface — bioshere — boundary layer observation sites, which may become desirable for the Globel Change programme.The data measured in situ should be intercompared with the data derived from space borne observations by one world ANCHOR STATION INTERCOMPARISON CENTER.

5. HOW ISLSCP DATA SETS CAN BE USED IN CLIMATE STUDIES

5.1. Global data sets for climate modelling

Climatological data sets developed on a 250 km × 250 km grid with weekly to seasonal time-resolution have two related uses. First, as input for model prescriptions of various aspects of land-surface prescriptions, and second, to check and if necessary adjust model parameterizations. In reality, the second use is the more important one, and is inevitably the application needed for any existing model. For example, any model where thought has been given to surface albedo will already have some prescription for surface albedo which would likely be adjusted with the availability of satellite data. Year-to-year changes in land-surface properties are of considerable interest in their own right, but GCM modelers will not be able to use such information satisfactorily until they have developed adequate treatments of land-surface processes.

In developing an implementation strategy for global data sets, emphasis should be given to those land-surface properties where a better description would likely give the largest improvements in model performance. The land-surface interacts with the climate system through fluxes of radiation and sensible and latent heat, so data that improve the inference of these fluxes should be emphasized. Radiative fluxes depend on the overlying atmosphere, and on surface albedo for the solar, on surface emissivity for the longwave part of the spectrum.

At present, GCMs model surface albedos on the basis of land-cover data derived from national atlases, and measured albedo values from individual sites. These procedures give albedos in GCMs with errors between 0.05 and 0.10 for monthly and regional averages. Current satellite estimates of surface albedo are expected to be uncertain by 0.05, so some improvement should be possible in present GCM prescriptions of surface albedo by application of satellite data. Better descriptions of bidirectional reflectances of the land-surface and better calibration of satellite observations should give rise to improved measurement of land-surface albedos.

The bulk of the evidence from GCM sensitivity studies indicates that modelled climates are more seriously degraded by uncertainty and inaccuracies in parameterizations of evapotranspiration than of albedo. Hence, we must especially establish global data sets that can improve this situation.

As already discussed, parameterizations of evapotranspiration depend on soil moisture within the rooting zone of plants, properties of the vegetation canopy including its aerodynamic roughness, energy balance of the plant canopy and properties of the overlying atmosphere, i.e., wind, temperature, and water vapor concentration. These inputs are largely not directly available from satellite observations.

The notable exception is vegetation cover. Any detailed model of evapotranspiration requires some description of seasonally varying vegetation cover, either as input or generated within the model. Such information could be made available from satellite (AVHRR or SMMR) estimates of vegetation index. No calibration of these measurements is available except locally through ground-truth measurements.

In particular, maximum and minimum vegetation cover is not readily estimated from these measurements. However, the satellite measurements of vegetation can provide a relative seasonal cycle and so be combined with independent estimates of vegetation cover to provide or test model estimates of the seasonal variation of vegetation.

A second important global data set to emphasize is that of the diurnal variation of surface skin temperature which, in principle, is available either from sounder or imager data. The procedure for obtaining this parameter using HIRS/MSU sounder data as analyzed for July and January for 1979 and 1982 (Figure 5.1) has not yet been validated.

Day-night temperature skin variation has also been analyzed from AVHRR window data and from the GOES imager thermal channel to infer soil moisture properties, but only for local sites.

Potentially, the most complete global land-surface data sets would come as part of the data analyses of numerical forecast centers, since optimum analyses of the atmosphere and distribution of rainfall are needed for analyses of soil moisture. However, this will only happen when inclusion of land-surface processes becomes an important part of forecasting procedures. Hence, ISLSCP should support the rapid development of the capability within forecast centers of including land-surface processes, and sensitivity studies should be carried out to establish the priority of this effort for improving forecasts. Soil moisture becomes an especially important prognostic variable to focus on, and seasonal variations in vegetation cover could also become a significant requirement.

5.2. Diagnosing climate trends and global change

Long term ISLSCP data sets will become an important tool for quantifying changes that occur at the Earth's surface and can be identified by means of spectral reflectances or emittances. Also in the microwave region, the polarization yields a measure of certain surface features. Long term ISLSCP data sets would reveal changes in vegetation such as the removal of rain forests, progressive desertification, erosion and changes in soil moisture. They would also, if properly calibrated, allow these changes to be quantified and their effect on the surface-atmosphere interaction to be estimated.

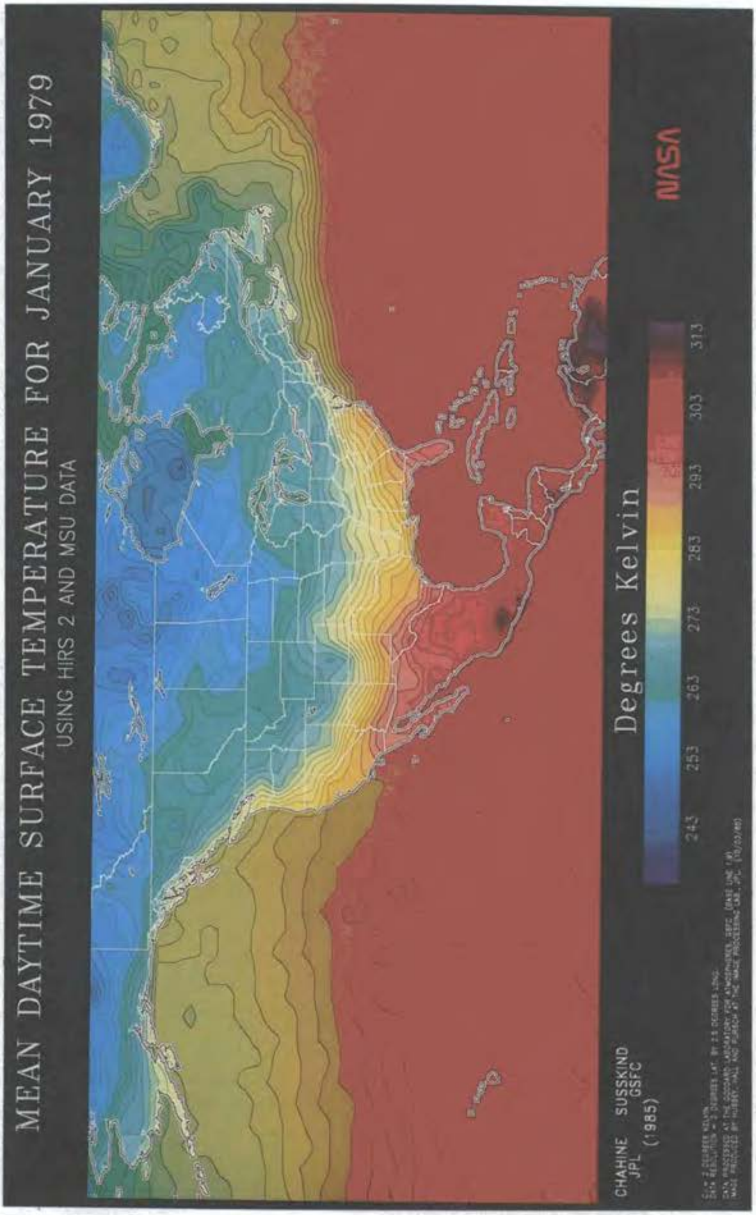

Fig. 5.1 a Mean daytime temperature for January 1979 (by courtesy of M. T. Chahine and J. Susskind).

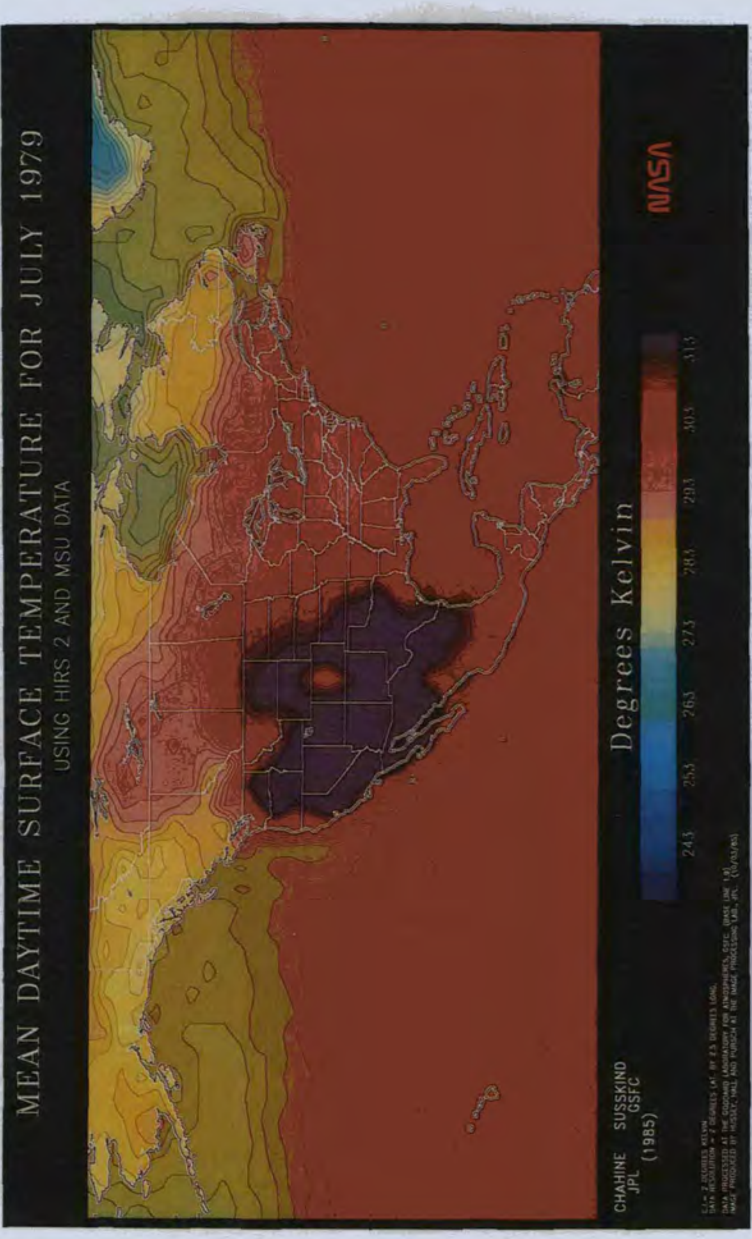

Fig. 5.1 b Mean daytime temperature for July 1979 (by courtesy of M. T. Chahine and J. Susskind).

The temperatures of surfaces which are not affected by other processes will be directly relevant for climate, but generally supplemental data will be needed to discriminate between man-induced changes, wild-life effects and climate trends. For the latter it would be necessary to establish data records which are long enough to filter out interannual variations. This will take more than ten years.

Continuous measurements will also allow the study of the dynamics involved in these processes. Desertification is an example of a discontinuous process. It may advance in one area and recede in another. Phases of recovery may interrupt the process. Thus the understanding and the description of these processes will develop. It may even turn out that because of the integrating character of land-surface hydrological processes the changes of the land-surface may be an indicator of the local impact of a rising global mean temperature due to the increasing amount of greenhouse gases in the atmosphere.

ISLSCP data sets may also provide information on the change of biomass and biomass production thus contributing to our knowledge of the carbon budget. The determination of the sizes of wetland cultures will furthermore contribute to efforts estimating the global methane production. Paddy fields can easily be recognized by the time variation in the vegetation index.

5.3. Impact studies

ISLSCP was primarily established to support climate impact studies within the WCP. During the first years of its existence, its major concern was to develop methods to infer certain surface properties and to validate these products. This aspect is still important. A number of regional studies have been undertaken (and are documented in the Proceedings of the Rome conference, 1985) while a global assessment is still somewhat further ahead. The problem with impact studies is that an intercomparison, for instance of one week in one year and the same week in another year does not necessarily reveal an interannual change. The development in time has to be observed as well. A climatic change can shorten or prolong growing seasons, can cause a vegetation stress to occur earlier in the year or modify the distribution of precipitation causing a deviation of hydrological processes from normal. Research in this direction should be started as soon as the first long time series become available such as the vegetation index and albedo maps of Africa or the time series of vegetation indices for Europe (1983—1985). The studies can be started with a drought year that is likely to reflect a warmer climate situation in comparison to "normal" years. Great care has to be taken into account for the technological impact, such as irrigation, on the results. It therefore seems mandatory that such satellite data application studies be accompanied by in situ surveys.

6. OUTLOOK

The feasibility of producing global data sets has been demonstrated with the following products:

- global cloud climatology (Figure 6.1)
- global NDVI from AVHRR data (Figure 6.2)
- global microwave vegetation index (Figure 2.24)
- global surface temperature data sets and interannual variability from HIRS data (Figure 2.29)
- global albedo from Nimbus 3 (Figure 2.6a)

Fig. 6.1 ISCCP-cloud climatology (by courtesy of NASA Goddard Space Flight Center, Institute for Space Studies).

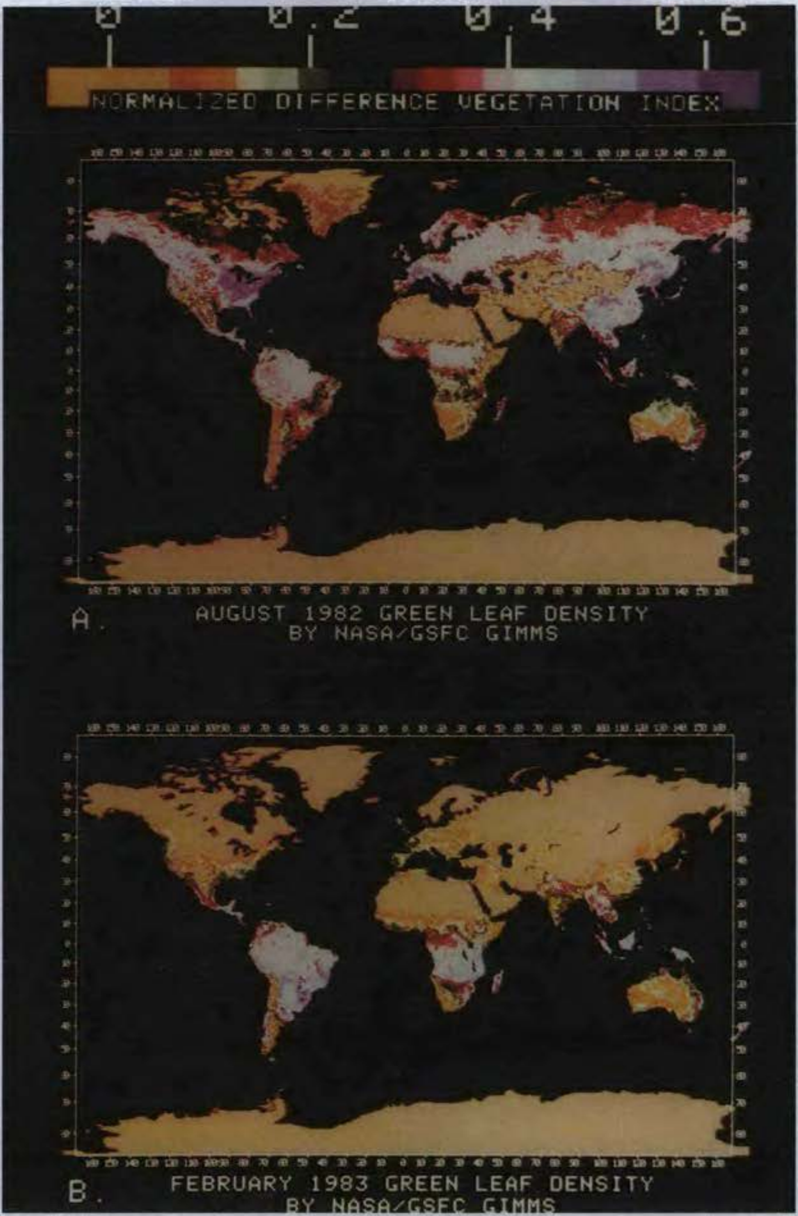

Fig. 6.2 Global normalized difference vegetation index (green leaf density) for August 1982 and February 1983 (from C. J. Tucker et al., 1986).

On a continental scale data sets of higher resolution have also become available, as demonstrated by

- albedo maps for Africa (Figure 2.1)
- snow maps for the northern hemisphere (Figure 6.3)
- three years vegetation index for Europe (Fig. 2.11)
- mean daytime surface temperatures from HIRS and MSU data (Figures 2.7 and 2.8).

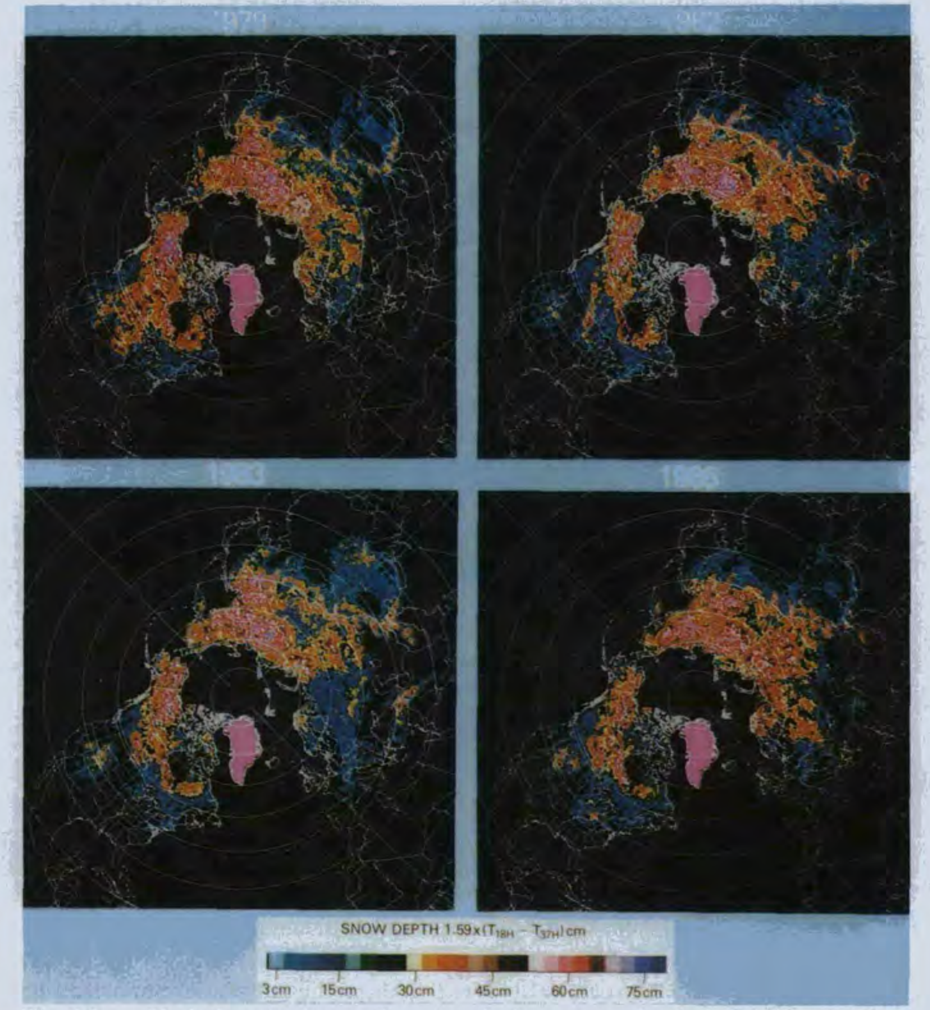

Fig. 6.3 Variations in the northern hemisphere snow depth derived from Nimbus 7 SMMR for February 1979, 1982, 1983 and 1985 (from A. T. C. Chang, GSFC, published by S. I. Rasool, 1987).

The most carefully selected algorithms have so far been applied to studies of cloud climatology. The time that elapsed between the establishment of the original specification (1978) and the availability of the first data sets in 1987 was nine years. During this time, the algorithms had to be refined, intercompared and the best methods selected. Then the four space agencies involved had to be instructed how to sample the data, the funds for the project had to be raised and a central facility had to be established for the final retrieval of the cloud information. The project includes an intercalibration method and a research program to validate the data and to intercompare the products with ground observations.

The ISLSCP products are presently still based upon individual algorithms which have not yet been intercompared and accepted by a wider scientific community and only in a few instances have they been validated by ground observations (Figure 6.4). However, a small number of experiments at the ground have now been performed (FIFE, HAPEX-MOBILHY, La Crau) and a few will follow in 1988, all of which will provide data sets for an intercomparison with satellite products. The availability of these data provides the basis for a rigorous assessment of the accuracy of current algorithms and offer the possibility of intercomparison of different approaches. Two proposals for HAPEX type experiments are at present under discussion, one in Niger, Africa, and one in China at the Heihe river. At a workshop in Yalta, October 1987, a contribution of the U.S.S.R. was under discussion. The future plans are summarized in Figure 6.5.

From the experiments which have been completed so far and are planned for the next few years, it can be expected that we will improve

- our knowledge about the achievable accuracy of satellite data evaluation,
- our understanding of the spatial and temporal variability of land-surface characteristics and its consequences for data sampling, and
- the availability of data sets for model studies and the improvement of the parameterization of land-surface processes.

The experimental data will provide much more detailed insight into the different land-surface processes that interact with each other. It is expected that from there new momentum will come for the improvement of models. We will also learn much about the sampling problem that will affect the specifications for future data needs.

The evaluation of the experimental and collocated satellite data will last for at least one year, and it cannot be expected that generally agreed recommendations about the evaluation methods for satellite measurements will emerge before mid 1989.

In parallel to the evaluation of the fields experiments the further development and improvement of evaluation methods will be promoted and at a workshop planned in 1990 it may be possible to decide upon standardized algorithms. Data sets to test candidate algorithms have to be defined in detail during 1988/1989. This includes

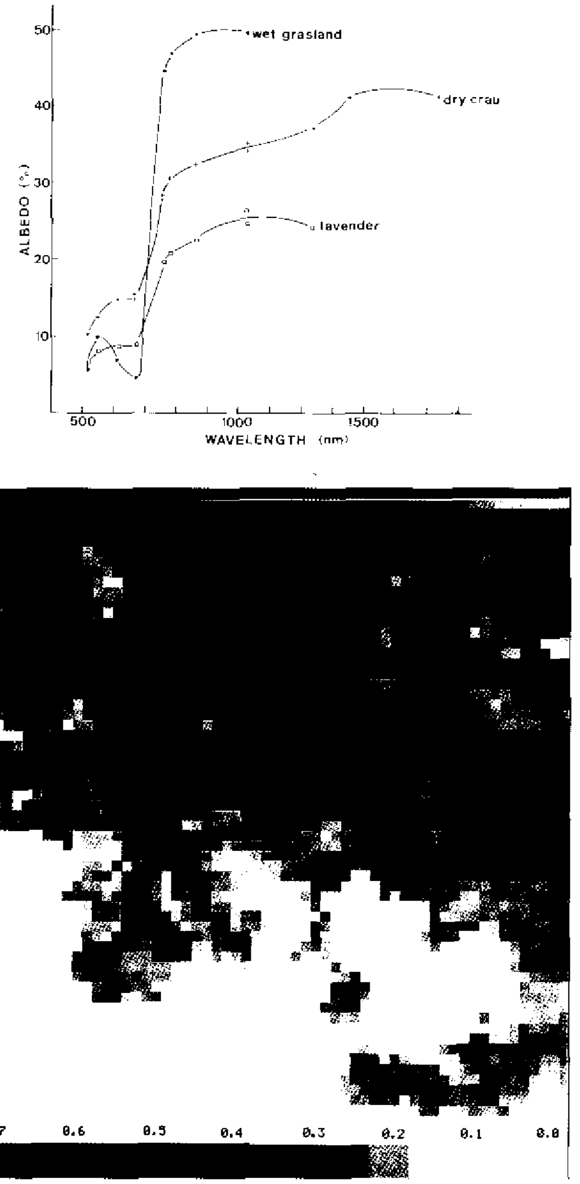

Fig. 6.4 First results from European experiments in La Crau — June 1987: (a) spectral albedo of three different test areas, (b) vegetation index (NDVI) of La Crau, 2 June 1987.

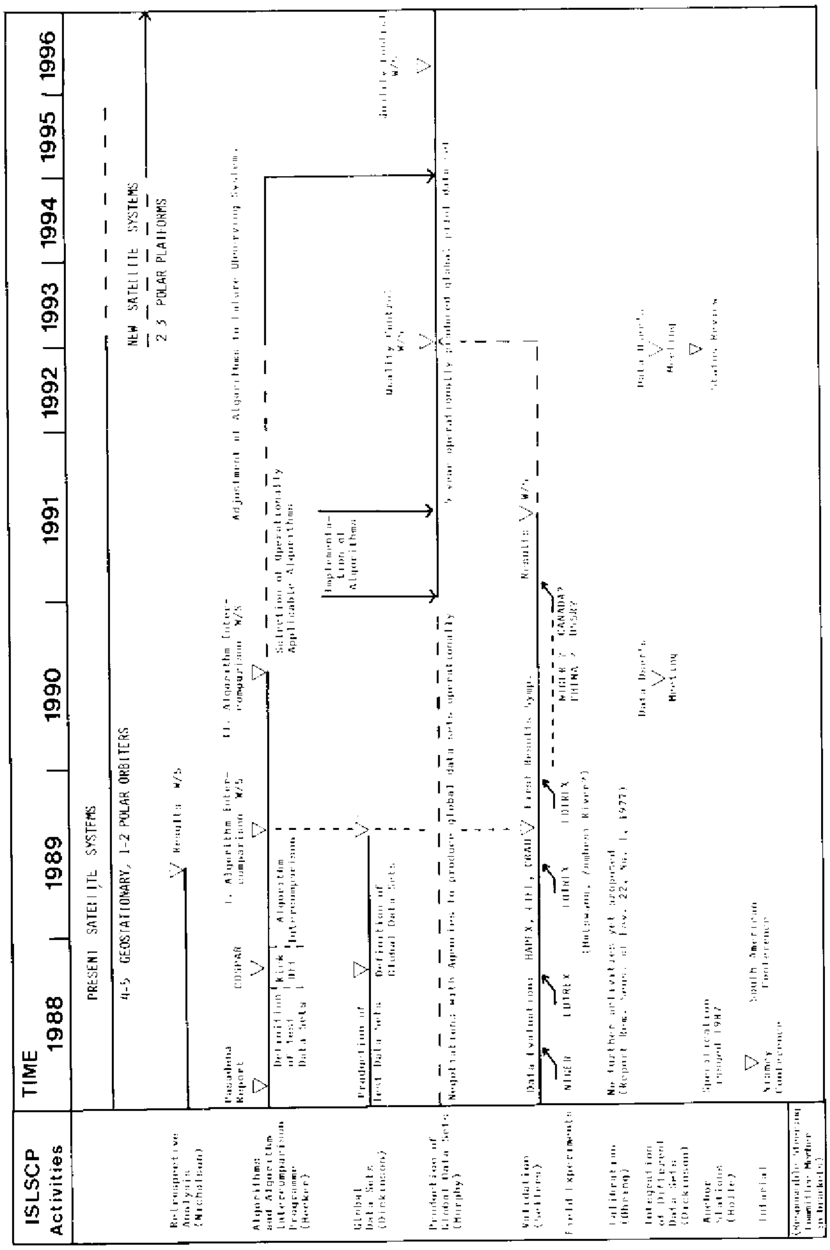

Fig. 6.5 Future plans of ISLSCP.

decisions such as what quantities are needed, spatial and temporal resolution and format of data archives.

In the meantime negotiations will start with the different space agencies about the production of global data sets. The production of pilot data sets should start in 1991 so that at least four to five years of data may be obtained before the present satellite observing system ceases. In the mid nineties it will probably be replaced by a new system with different sensors. The evaluation methods must be adjusted to the new sensor systems and their extended capabilities. This change of the observation system will necessitate a new series of validation experiments during the late nineties. In this phase the proposed anchor stations may become an essential tool for quality control.

A major task will be the combination of different data products in order to improve the value of the satellite observations. This data-merging will involve different products such as instantaneous albedo and temperature observations, and the mixing of satellite data with operational meteorological or climatological data. The combination of such data sets with conventional information on land-use, soil properties, yield and water/energy consumption must also be addressed. This is the point where the need for geographically coded information systems enters the ISLSCP. These computer-aided archives will hopefully be developed to a point where they can successfully be applied for this purpose.

ISLSCP must also provide for the distribution of knowledge about the programme and encourage scientists from many countries and disciplines to participate in the basic research and in the use of the data. For this purpose tutorial meetings and courses are planned from time to time in different parts of the world.

An important value of the project that is already emerging is furthermore that it stimulates biologists, geographers, geologists, hydrologists, meteorologists, soil physicists and system engineers to combine their knowledge, skill and "energy" so as to understand better the global system that is our planet.

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LIST OF ACRONYMS

ACZCS	Advanced Costal Zone Color Scanner
AMI	Advanced Mirowave Instrument
AMS	Automatic Meteorological Station
AMSU	Advanced Microwave Sounding Unit
ASTR	Advanced Sea-Surface Temperature Radiometer
AVHRR	Advanced Very-High Resolution Radiometer
BDR	Bidirectional Reflectance
COSPAR	COmmittee on SPAce Research (of ICSU)
CNES	Centre National d'Etudes Spatiales (France)
CNRS	Centre National de la Recherche Scientifique (France)
DMSP	Defense Meteorological Satellite Project
EARSEL	European Association of Remote SEnsing Laboratories
ERBE	Earth Radiation Budget Experiment
ERS	First European Remote Sensing Satellite
ESA	European Space Agency
ESOC	European Space Operation Center
FAO	Food and Agricultural Organization (U.N.)
FIFE	First ISLSCP Field Experiment
GAMP	Group Agromet Monitoring Project
GCM	General Circulation Model
GEWEX	Global Energy and Water-Cycle Experiment
GIMMS	Global Inventory Monitoring and Modelling Studies (NASA)
GMT	Greenwich Mean Time
GOES	Geostationary Operational Environmental Satellite (U.S.)
GSFC	Goddard Space Flight Center (NASA, U.S.)
GSTS	Groupement Scientifique de Télédéction
HAPEX	Hydrological Atmospheric Pilot Experiments
HIRS	High-resolution InfraRed Sounder (U.S.)
HIRIS	High-resolution Imaging Spectrometer
HMMR	High-resolution Multifrequency Microwave Radiometer
IAMAP	International Association of Meteorology and Atmospheric Physics of IUGG
ICSU	International Council of Scientific Unions
IFOV	Instantaneous Field Of View
IGBP	International Geosphere-Biosphere Program
INRA	Institut National de la Recherche Agronomique
IR	Infrared
ISCCP	International Satellite Cloud Climatology Project
ISLSCP	International Satellite Land-Surface Climatology Project
IUGG	International Union of Geodesy and Geophysics
JPL	Jet Propulsion Laboratory (NASA, U.S.)
JSC	Joint Scientific Committee (ICSU and WMO, for the WCRP)
LAI	Leaf Area Index
LANDSAT	Earth resources satellite (U.S.)
LE	Latent Energy (Evapotranspiration)

LERTS	Laboratoire d'Études et de Recherches en Teledetection Spatiale
LIDAR	Light detection and ranging instrument
LOTREX	LOngitudinal land-surface TRaverse EXperiment
MESSR	Multispectral Electronic Self-Scanning Radiometer
METEOSAT	European geostationary meteorological satellite
MOBILHY	MOdele de BILan HYdrique (French Stream 2 experiment in the frame of PNEDC)
MODIS	Moderate-Resolution Imaging Spectrometer
MOS	Marine Observation Satellite (Japan)
MSR	MOS: Microwave Scanning Radiometer METEOSAT: METEOSAT Scanning Radiometer
MSS	Multi-Spectral Scanner (U.S.)
MSU	Microwave Sounding Unit (U.S.)
NAE	National Aeronautical Establishment
NASA	National Aeronautical and Space Administration
NCAR	National Center for Atmospheric Research
NDVI	Normalized Difference Vegetation Index
NESDIS	National Environmental Satellite Data and Information Service (NOAA, U.S.)
NIR	Near Infrared
NOAA	National Oceanic and Atmospheric Administration (U.S.)
NSF	National Science Foundation
OLS	Operational Linescan System
PAR	Photosynthetically Active Radiation
Pixel	Picture Element
RBV	Return Beam Videcon
SAR	Synthetic Aperture Radar
SMMR	Scanning Multichannel Microwave Radiometer
SOP	Special Observing Period
SPOT	Satellite Probatoire d'Observation de la Terre (test earth observation system, France)
SR(VI)	Simple Ratio Vegetation Index
TIROS	Television Infrared Operational Satellite (the first series of NOAA meteorological satellites)
TM	Thematic Mapper
TOVS	TIROS Operational Vertical Sounder
UNEP	United Nations Environmental Programme
VAS	VISSR Atmospheric Sounder
VI	Vegetation Index
VIS	Visible part of the spectrum
VISSR	Visible-Infrared Spin-Scan Radiometer
VTIR	Visible and Thermal Infrared Radiometer
WCIP	World Climate Impact studies Programme
WCP	World Climate Programme
WCRP	World Climate Research Programme (ICSU and WMO)
WMO	World Meteorological Organization